

(12) **United States Patent**
Bertness

(10) **Patent No.:** **US 9,274,157 B2**
(45) **Date of Patent:** **Mar. 1, 2016**

(54) **BATTERY TESTER FOR ELECTRIC VEHICLE**

(75) Inventor: **Kevin I. Bertness**, Batavia, IL (US)

(73) Assignee: **Midtronics, Inc.**, Willowbrook, IL (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 383 days.

(2013.01); **B60L 11/14** (2013.01); **B60L 11/1857** (2013.01); **B60L 11/1866** (2013.01); **B60L 2240/36** (2013.01); **B60L 2250/16** (2013.01); **G01R 31/3624** (2013.01); **Y02T 10/70** (2013.01); **Y02T 10/7005** (2013.01); **Y02T 10/7022** (2013.01); **Y02T 10/7061** (2013.01); **Y02T 10/7077** (2013.01)

(58) **Field of Classification Search**
CPC combination set(s) only.
See application file for complete search history.

(21) Appl. No.: **12/888,689**

(56) **References Cited**

(22) Filed: **Sep. 23, 2010**

U.S. PATENT DOCUMENTS

(65) **Prior Publication Data**

US 2011/0015815 A1 Jan. 20, 2011

85,553 A	1/1869 Adams	33/472
2,000,665 A	5/1935 Neal	439/440
2,417,940 A	3/1947 Lehman	200/61.25

(Continued)

Related U.S. Application Data

FOREIGN PATENT DOCUMENTS

(63) Continuation-in-part of application No. 12/174,894, filed on Jul. 17, 2008, now Pat. No. 8,306,690.

CN	2470964 Y	1/2002
CN	201063352 Y	5/2008

(60) Provisional application No. 60/970,319, filed on Sep. 6, 2007, provisional application No. 60/950,182, filed on Jul. 17, 2007.

(Continued)

OTHER PUBLICATIONS

(51) **Int. Cl.**
B60L 1/00 (2006.01)
G01R 31/00 (2006.01)
B60L 1/02 (2006.01)
B60L 1/14 (2006.01)
B60L 3/00 (2006.01)
B60L 3/12 (2006.01)
B60L 7/18 (2006.01)
B60L 11/00 (2006.01)
B60L 11/14 (2006.01)

“Electrochemical Impedance Spectroscopy in Battery Development and Testing”, *Batteries International*, Apr. 1997, pp. 59 and 62-63.

(Continued)

Primary Examiner — Jonathan L Sample

(74) Attorney, Agent, or Firm — Westman, Champlin & Koehler, P.A.

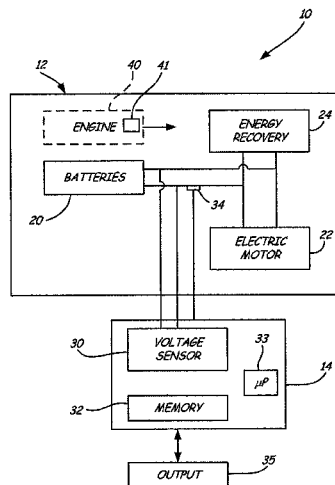
(57) **ABSTRACT**

Testing or diagnostics are performed on an electric vehicle. The vehicle is operated and current flow through a system of the vehicle is monitored. A voltage related to the system is also monitored. Diagnostics are provided based upon the monitored voltage and the monitored current.

42 Claims, 4 Drawing Sheets

(52) **U.S. Cl.**
CPC **G01R 31/007** (2013.01); **B60L 1/003** (2013.01); **B60L 1/02** (2013.01); **B60L 1/14** (2013.01); **B60L 3/0046** (2013.01); **B60L 3/12** (2013.01); **B60L 7/18** (2013.01); **B60L 11/005**

(Continued)



- (51) **Int. Cl.**
B60L 11/18 (2006.01)
G01R 31/36 (2006.01)

(56) **References Cited**

U.S. PATENT DOCUMENTS

2,437,772 A 3/1948 Wall 324/523
 2,514,745 A 7/1950 Dalzell 324/115
 2,727,221 A 12/1955 Springg 340/447
 3,025,455 A 3/1962 Jonsson 323/369
 3,178,686 A 4/1965 Mills 340/447
 3,215,194 A 11/1965 Sununu et al. 165/80.3
 3,223,696 A 12/1965 Alexander 340/447
 3,267,452 A 8/1966 Wolf 340/249
 3,356,936 A 12/1967 Smith 324/429
 3,562,634 A 2/1971 Latner 324/427
 3,593,099 A 7/1971 Scholl 320/127
 3,607,673 A 9/1971 Seyl 324/425
 3,652,341 A 3/1972 Halsall et al. 29/623.2
 3,676,770 A 7/1972 Sharaf et al. 324/430
 3,699,433 A 10/1972 Smith, Jr. 324/523
 3,729,989 A 5/1973 Little 73/862.192
 3,750,011 A 7/1973 Kreps 324/430
 3,753,094 A 8/1973 Furuishi et al. 324/430
 3,776,177 A 12/1973 Bryant et al. 116/311
 3,796,124 A 3/1974 Crosa 411/521
 3,808,522 A 4/1974 Sharaf 324/430
 3,811,089 A 5/1974 Strezelewicz 324/170
 3,816,805 A 6/1974 Terry 320/123
 3,850,490 A 11/1974 Zehr 439/822
 3,857,082 A 12/1974 Van Opijnen 320/143
 3,873,911 A 3/1975 Champlin 324/430
 3,876,931 A 4/1975 Godshalk 324/429
 3,886,426 A 5/1975 Daggett 320/117
 3,886,443 A 5/1975 Miyakawa et al. 324/426
 3,889,248 A 6/1975 Ritter 340/636.11
 3,906,329 A 9/1975 Bader 320/134
 3,909,708 A 9/1975 Champlin 324/431
 3,920,284 A 11/1975 Lane et al. 303/122.06
 3,936,744 A 2/1976 Perlmuter 324/772
 3,946,299 A 3/1976 Christianson et al. 320/430
 3,947,757 A 3/1976 Grube et al. 324/416
 3,969,667 A 7/1976 McWilliams 324/427
 3,979,664 A 9/1976 Harris 324/397
 3,984,762 A 10/1976 Dowgiallo, Jr. 324/430
 3,984,768 A 10/1976 Staples 324/712
 3,989,544 A 11/1976 Santo 429/65
 3,997,830 A 12/1976 Newell et al. 320/102
 4,008,619 A 2/1977 Alcaide et al. 73/724
 4,023,882 A 5/1977 Pettersson 439/426
 4,024,953 A 5/1977 Nailor, III 206/344
 4,047,091 A 9/1977 Hutchines et al. 363/59
 4,053,824 A 10/1977 Dupuis et al. 324/434
 4,056,764 A 11/1977 Endo et al. 320/101
 4,057,313 A 11/1977 Polizzano 439/219
 4,070,624 A 1/1978 Taylor 324/772
 4,086,531 A 4/1978 Bernier 324/772
 4,106,025 A 8/1978 Katz 343/715
 4,112,351 A 9/1978 Back et al. 324/380
 4,114,083 A 9/1978 Benham et al. 340/636.13
 4,126,874 A 11/1978 Suzuki et al. 396/301
 4,160,916 A 7/1979 Papasideris 307/10.6
 4,178,546 A 12/1979 Hulls et al. 324/772
 4,193,025 A 3/1980 Frailing et al. 324/427
 4,207,610 A 6/1980 Gordon 701/33.9
 4,207,611 A 6/1980 Gordon 701/33
 4,217,645 A 8/1980 Barry et al. 702/63
 4,218,745 A 8/1980 Perkins 324/66
 4,280,457 A 7/1981 Bloxham 123/198 R
 4,297,639 A 10/1981 Branham 324/429
 4,307,342 A 12/1981 Peterson 324/767
 4,315,204 A 2/1982 Sievers et al. 322/28
 4,316,185 A 2/1982 Watrous et al. 340/636.11
 4,322,685 A 3/1982 Frailing et al. 324/429
 4,351,405 A 9/1982 Fields et al. 180/65.2
 4,352,067 A 9/1982 Ottone 324/434

4,360,780 A 11/1982 Skutch, Jr. 324/437
 4,361,809 A 11/1982 Bil et al. 324/426
 4,363,407 A 12/1982 Buckler et al. 209/3.3
 4,369,407 A 1/1983 Korbell 324/416
 4,379,989 A 4/1983 Kurz et al. 320/165
 4,379,990 A 4/1983 Sievers et al. 322/99
 4,385,269 A 5/1983 Aspinwall et al. 320/129
 4,390,828 A 6/1983 Converse et al. 320/153
 4,392,101 A 7/1983 Saar et al. 320/156
 4,396,880 A 8/1983 Windebank 320/156
 4,408,157 A 10/1983 Beaubien 324/712
 4,412,169 A 10/1983 Dell'Orto 320/123
 4,423,378 A 12/1983 Marino et al. 324/427
 4,423,379 A 12/1983 Jacobs et al. 324/429
 4,424,491 A 1/1984 Bobbett et al. 324/433
 4,425,791 A 1/1984 Kling 73/116.02
 4,441,359 A 4/1984 Ezoe 73/116.06
 4,459,548 A 7/1984 Lentz et al. 324/472
 4,514,694 A 4/1985 Finger 324/429
 4,520,353 A 5/1985 McAuliffe 340/636.16
 4,521,498 A 6/1985 Juergens 429/59
 4,564,798 A 1/1986 Young 320/103
 4,620,767 A 11/1986 Woolf 439/217
 4,633,418 A 12/1986 Bishop 702/63
 4,637,359 A 1/1987 Cook 123/179
 4,659,977 A 4/1987 Kissel et al. 320/150
 4,663,580 A 5/1987 Wortman 320/153
 4,665,370 A 5/1987 Holland 324/429
 4,667,143 A 5/1987 Cooper et al. 320/153
 4,667,279 A 5/1987 Maier 363/46
 4,678,998 A 7/1987 Muramatsu 324/427
 4,679,000 A 7/1987 Clark 324/428
 4,680,528 A 7/1987 Mikami et al. 320/165
 4,686,442 A 8/1987 Radomski 320/123
 4,697,134 A 9/1987 Burkum et al. 320/134
 4,707,795 A 11/1987 Alber et al. 702/63
 4,709,202 A 11/1987 Koenck et al. 320/112
 4,710,861 A 12/1987 Kanner 363/46
 4,719,428 A 1/1988 Liebermann 324/436
 4,723,656 A 2/1988 Kiernan et al. 206/705
 4,743,855 A 5/1988 Randin et al. 324/430
 4,745,349 A 5/1988 Palanisamy et al. 320/125
 4,773,011 A 9/1988 VanHoose 701/30
 4,781,629 A 11/1988 Mize 439/822
 D299,909 S 2/1989 Casey D10/77
 4,816,768 A 3/1989 Champlin 324/428
 4,820,966 A 4/1989 Fridman 320/116
 4,825,170 A 4/1989 Champlin 324/436
 4,847,547 A 7/1989 Eng, Jr. et al. 320/153
 4,849,700 A 7/1989 Morioka et al. 324/427
 4,874,679 A 10/1989 Miyagawa 429/91
 4,876,495 A 10/1989 Palanisamy et al. 320/106
 4,881,038 A 11/1989 Champlin 324/426
 4,885,523 A 12/1989 Koench 230/131
 4,888,716 A 12/1989 Ueno 702/63
 4,901,007 A 2/1990 Sworm 324/110
 4,907,176 A 3/1990 Bahnick et al. 364/551.01
 4,912,416 A 3/1990 Champlin 324/430
 4,913,116 A 4/1990 Katogi et al. 123/406.32
 4,926,330 A 5/1990 Abe et al. 701/33
 4,929,931 A 5/1990 McCuen 340/636.15
 4,931,738 A 6/1990 MacIntyre et al. 324/435
 4,932,905 A 6/1990 Richards 439/822
 4,933,845 A 6/1990 Hayes 708/104
 4,934,957 A 6/1990 Bellusci 439/504
 4,937,528 A 6/1990 Palanisamy 324/430
 4,947,124 A 8/1990 Hauser 324/430
 4,949,046 A 8/1990 Seyfang 324/427
 4,956,597 A 9/1990 Heavey et al. 320/129
 4,965,738 A 10/1990 Bauer et al. 320/136
 4,968,941 A 11/1990 Rogers 324/428
 4,968,942 A 11/1990 Palanisamy 324/430
 4,969,834 A 11/1990 Johnson 439/141
 4,983,086 A 1/1991 Hatrock 411/259
 5,004,979 A 4/1991 Marino et al. 324/160
 5,030,916 A 7/1991 Bokitch 324/503
 5,032,825 A 7/1991 Kuznicki 340/636.15
 5,034,893 A 7/1991 Fisher 701/99
 5,037,778 A 8/1991 Stark et al. 228/121

(56)

References Cited

U.S. PATENT DOCUMENTS

5,047,722 A	9/1991	Wurst et al.	324/430	5,453,027 A	9/1995	Buell et al.	439/433
5,081,565 A	1/1992	Nabha et al.	362/465	5,457,377 A	10/1995	Jonsson	324/430
5,087,881 A	2/1992	Peacock	324/378	5,459,660 A	10/1995	Berra	713/33
5,095,223 A	3/1992	Thomas	307/110	5,469,043 A	11/1995	Cherng et al.	320/161
5,108,320 A	4/1992	Kimber	439/883	5,485,090 A	1/1996	Stephens	324/433
5,109,213 A	4/1992	Williams	340/447	5,488,300 A	1/1996	Jamieson	324/432
5,126,675 A	6/1992	Yang	324/435	5,504,674 A	4/1996	Chen et al.	705/4
5,130,658 A	7/1992	Bohmer	324/435	5,508,599 A	4/1996	Koenck	320/138
5,140,269 A	8/1992	Champlin	324/433	5,519,383 A	5/1996	De La Rosa	340/636.15
5,144,218 A	9/1992	Bosscha	320/139	5,528,148 A	6/1996	Rogers	320/137
5,144,248 A	9/1992	Alexandres et al.	324/428	5,537,967 A	7/1996	Tashiro et al.	123/192.1
D330,338 S	10/1992	Wang	D10/77	5,541,489 A	7/1996	Dunstan	320/134
5,159,272 A	10/1992	Rao et al.	324/429	5,546,317 A	8/1996	Andrieu	702/63
5,160,881 A	11/1992	Schramm et al.	327/7	5,548,273 A	8/1996	Nicol et al.	340/439
5,164,653 A	11/1992	Reem		5,550,485 A	8/1996	Falk	324/772
5,168,208 A	12/1992	Schultz et al.	322/25	5,561,380 A	10/1996	Sway-Tin et al.	324/509
5,170,124 A	12/1992	Blair et al.	324/434	5,562,501 A	10/1996	Kinoshita et al.	439/852
5,179,335 A	1/1993	Nor	320/159	5,563,496 A	10/1996	McClure	320/128
5,187,382 A	2/1993	Kondo		5,572,136 A	11/1996	Champlin	324/426
5,194,799 A	3/1993	Tomantschger	320/103	5,573,611 A	11/1996	Koch et al.	152/152.1
5,204,611 A	4/1993	Nor et al.	320/145	5,574,355 A	11/1996	McShane et al.	320/161
5,214,370 A	5/1993	Harm et al.	320/152	5,578,915 A	11/1996	Crouch, Jr. et al.	324/428
5,214,385 A	5/1993	Gabriel et al.	324/434	5,583,416 A	12/1996	Klang	320/160
5,223,747 A	6/1993	Tschulena	257/713	5,585,416 A	12/1996	Audett et al.	522/35
5,241,275 A	8/1993	Fang	324/430	5,585,728 A	12/1996	Champlin	324/427
5,254,952 A	10/1993	Salley et al.	324/429	5,589,757 A	12/1996	Klang	320/160
5,266,880 A	11/1993	Newland	320/125	5,592,093 A	1/1997	Klingbiel	324/426
5,278,759 A	1/1994	Berra et al.	701/1	5,592,094 A	1/1997	Ichikawa	24/427
5,281,919 A	1/1994	Palanisamy	324/427	5,596,260 A	1/1997	Moravec et al.	320/135
5,281,920 A	1/1994	Wurst	324/430	5,596,261 A	1/1997	Suyama	320/152
5,295,078 A	3/1994	Stich et al.	700/297	5,598,098 A	1/1997	Champlin	324/430
5,298,797 A	3/1994	Redl	327/387	5,602,462 A	2/1997	Stich et al.	323/258
5,300,874 A	4/1994	Shimamoto et al.	320/106	5,606,242 A	2/1997	Hull et al.	320/106
5,302,902 A	4/1994	Groehl	324/434	5,614,788 A	3/1997	Mullins et al.	315/82
5,313,152 A	5/1994	Wozniak et al.	320/118	5,621,298 A	4/1997	Harvey	320/134
5,315,287 A	5/1994	Sol	340/455	5,631,536 A	5/1997	Tseng	320/15
5,321,626 A	6/1994	Palladino	702/63	5,631,831 A *	5/1997	Bird	G01M 15/05
5,321,627 A	6/1994	Reher	702/63				701/102
5,323,337 A	6/1994	Wilson et al.	702/73	5,633,985 A	5/1997	Severson et al.	704/267
5,325,041 A	6/1994	Briggs	320/149	5,637,978 A	6/1997	Kellett et al.	320/104
5,331,268 A	7/1994	Patino et al.	320/158	5,642,031 A	6/1997	Brotto	320/156
5,332,927 A	7/1994	Paul et al.	307/66	5,644,212 A	7/1997	Takahashi	
5,336,993 A	8/1994	Thomas et al.	324/158.1	5,650,937 A	7/1997	Bounaga	702/65
5,338,515 A	8/1994	Dalla Betta et al.	422/95	5,652,501 A	7/1997	McClure et al.	340/636.15
5,339,018 A	8/1994	Brokaw	320/147	5,653,659 A	8/1997	Kunibe et al.	477/111
5,343,380 A	8/1994	Champlin	363/46	5,654,623 A	8/1997	Shiga et al.	320/106
5,345,384 A *	9/1994	Przybyla	G07C 5/0808	5,656,920 A	8/1997	Cherng et al.	324/431
			701/29.1	5,661,368 A	8/1997	Deol et al.	315/82
5,347,163 A	9/1994	Yoshimura	307/66	5,666,040 A	9/1997	Bourbeau	320/118
5,352,968 A	10/1994	Reni et al.	320/136	5,675,234 A	10/1997	Greene	340/636.15
5,357,519 A	10/1994	Martin et al.	371/15.1	5,677,077 A	10/1997	Faulk	429/90
5,365,160 A	11/1994	Leppo et al.	320/160	5,684,678 A	11/1997	Barrett	363/17
5,365,453 A	11/1994	Startup et al.	702/36	5,691,621 A	11/1997	Phuoc et al.	320/134
5,369,364 A	11/1994	Renirie et al.	324/430	5,699,050 A	12/1997	Kanazawa	340/636.13
5,381,096 A	1/1995	Hirzel	324/427	5,701,089 A	12/1997	Perkins	324/772
5,384,540 A	1/1995	Dessel	324/539	5,705,929 A	1/1998	Caravello et al.	324/430
5,387,871 A	2/1995	Tsai	324/429	5,707,015 A	1/1998	Guthrie	241/120
5,394,093 A	2/1995	Cervas	324/556	5,710,503 A	1/1998	Sideris et al.	320/116
5,402,007 A	3/1995	Center et al.	90/40 B	5,711,648 A	1/1998	Hammerslag	414/800
5,410,754 A	4/1995	Klotzbach et al.	370/466	5,712,795 A	1/1998	Layman et al.	700/297
5,412,308 A	5/1995	Brown	323/267	5,717,336 A	2/1998	Basell et al.	324/430
5,412,323 A	5/1995	Kato et al.	324/429	5,717,937 A	2/1998	Fritz	713/300
5,425,041 A	6/1995	Seko et al.	372/45.01	5,721,688 A	2/1998	Bramwell	324/426
5,426,371 A	6/1995	Salley et al.	324/429	5,732,074 A	3/1998	Spaur et al.	370/313
5,426,416 A	6/1995	Jefferies et al.	340/664	5,739,667 A	4/1998	Matsuda et al.	320/128
5,430,645 A	7/1995	Keller	364/424.01	5,744,962 A	4/1998	Alber et al.	324/426
5,432,025 A	7/1995	Cox	429/65	5,745,044 A	4/1998	Hyatt, Jr. et al.	340/5.23
5,432,426 A	7/1995	Yoshida	320/160	5,747,189 A	5/1998	Perkins	429/91
5,434,495 A	7/1995	Toko	320/135	5,747,909 A	5/1998	Syverson et al.	310/156.56
5,435,185 A	7/1995	Eagan	73/587	5,747,967 A	5/1998	Muljadi et al.	320/148
5,442,274 A	8/1995	Tamai	320/146	5,754,417 A	5/1998	Nicollini	363/60
5,445,026 A	8/1995	Eagan	73/591	5,757,192 A	5/1998	McShane et al.	324/427
5,449,996 A	9/1995	Matsumoto et al.	320/148	5,760,587 A	6/1998	Harvey	324/434
5,449,997 A	9/1995	Gilmore et al.	320/148	5,772,468 A	6/1998	Kowalski et al.	439/506
5,451,881 A	9/1995	Finger	324/433	5,773,962 A	6/1998	Nor	320/134
				5,773,978 A	6/1998	Becker	324/430
				5,778,326 A	7/1998	Moroto et al.	701/22
				5,780,974 A	7/1998	Pabla et al.	315/82
				5,780,980 A	7/1998	Naito	318/139

(56)

References Cited

U.S. PATENT DOCUMENTS

5,789,899	A	8/1998	van Phuoc et al.	320/112	6,091,238	A	7/2000	McDermott	324/207.2
5,793,359	A	8/1998	Ushikubo	345/169	6,091,245	A	7/2000	Bertness	324/426
5,796,239	A	8/1998	van Phuoc et al.	320/107	6,094,033	A	7/2000	Ding et al.	320/132
5,808,469	A	9/1998	Kopera	324/434	6,097,193	A	8/2000	Bramwell	324/429
5,811,979	A	9/1998	Rhein	324/718	6,100,670	A	8/2000	Levesque	320/150
5,818,201	A	10/1998	Stockstad et al.	320/119	6,100,815	A	8/2000	Pailthorp	324/754.07
5,818,234	A	10/1998	McKinnon	324/433	6,104,167	A	8/2000	Bertness et al.	320/132
5,820,407	A	10/1998	Morse et al.	439/504	6,113,262	A	9/2000	Purola et al.	374/85
5,821,756	A	10/1998	McShane et al.	324/430	6,114,834	A	9/2000	Parise	320/109
5,821,757	A	10/1998	Alvarez et al.	324/434	6,121,880	A	9/2000	Scott et al.	340/572.5
5,825,174	A	10/1998	Parker	324/106	6,136,914	A	10/2000	Hergenrother et al.	524/495
5,831,435	A	11/1998	Troy	324/426	6,137,269	A	10/2000	Champlin	320/150
5,832,396	A	11/1998	Moroto et al.	701/22	6,140,797	A	10/2000	Dunn	320/105
5,850,113	A	12/1998	Weimer et al.	307/125	6,141,608	A *	10/2000	Rother	G01M 17/007
5,862,515	A	1/1999	Kobayashi et al.	702/63					701/29.1
5,865,638	A	2/1999	Trafton	439/288	6,144,185	A	11/2000	Dougherty et al.	320/132
5,869,951	A	2/1999	Takahashi	320/104	6,147,598	A	11/2000	Murphy et al.	340/426.19
5,870,018	A *	2/1999	Person	B60R 25/10	6,150,793	A	11/2000	Lesesky et al.	320/104
				307/10.2	6,158,000	A	12/2000	Collins	713/1
5,871,858	A	2/1999	Thomsen et al.	429/7	6,161,640	A	12/2000	Yamaguchi	180/65.8
5,872,443	A	2/1999	Williamson	320/160	6,163,156	A	12/2000	Bertness	324/426
5,872,453	A	2/1999	Shimoyama et al.	324/431	6,164,063	A	12/2000	Mendler	60/274
5,883,306	A	3/1999	Hwang	73/146.8	6,167,349	A	12/2000	Alvarez	702/63
5,884,202	A	3/1999	Arjomand	701/31.4	6,172,483	B1	1/2001	Champlin	320/134
5,895,440	A	4/1999	Proctor et al.	702/63	6,172,505	B1	1/2001	Bertness	324/430
5,903,154	A	5/1999	Zhang et al.	324/437	6,177,737	B1	1/2001	Palfev et al.	307/64
5,903,716	A	5/1999	Kimber et al.	395/114	6,181,545	B1	1/2001	Amatucci et al.	361/502
5,912,534	A	6/1999	Benedict	315/82	6,184,656	B1	2/2001	Karunasiri et al.	320/119
5,914,605	A	6/1999	Bertness	324/430	6,191,557	B1	2/2001	Gray et al.	320/132
5,916,287	A	6/1999	Arjomand et al.	701/33.2	6,202,739	B1	3/2001	Pal et al.	165/104.33
5,927,938	A	7/1999	Hammerslag	414/809	6,211,651	B1	4/2001	Nemoto	320/133
5,929,609	A	7/1999	Joy et al.	322/25	6,211,653	B1	4/2001	Stasko	320/132
5,935,180	A *	8/1999	Fieramosca	G01R 31/007	6,215,275	B1	4/2001	Bean	320/106
				324/133	6,218,805	B1	4/2001	Melcher	320/105
5,939,855	A	8/1999	Proctor et al.	320/104	6,218,936	B1	4/2001	Imao	340/447
5,939,861	A	8/1999	Joko et al.	320/122	6,222,342	B1	4/2001	Eggert et al.	320/105
5,945,829	A	8/1999	Bertness	324/430	6,222,369	B1	4/2001	Champlin	324/430
5,946,605	A	8/1999	Takahisa et al.	455/68	D442,503	S	5/2001	Lundbeck et al.	D10/77
5,950,144	A	9/1999	Hall et al.	702/108	6,225,808	B1	5/2001	Varghese et al.	324/426
5,951,229	A	9/1999	Hammerslag	414/398	6,225,898	B1 *	5/2001	Kamiya	G07C 5/008
5,953,322	A	9/1999	Kimball	370/328					340/10.1
5,955,951	A	9/1999	Wischerop et al.	340/572.8	6,236,186	B1	5/2001	Helton et al.	320/106
5,961,561	A	10/1999	Wakefield, II	701/29	6,236,332	B1	5/2001	Conkright et al.	340/3.1
5,961,604	A	10/1999	Anderson et al.	709/229	6,236,949	B1	5/2001	Hart	702/64
5,963,012	A	10/1999	Garcia et al.	320/106	6,238,253	B1	5/2001	Qualls	439/759
5,969,625	A	10/1999	Russo	340/636.19	6,242,887	B1	6/2001	Burke	320/104
5,973,598	A	10/1999	Beigel	340/572.1	6,249,124	B1	6/2001	Bertness	324/426
5,978,805	A	11/1999	Carson	707/10	6,250,973	B1	6/2001	Lowery et al.	439/763
5,982,138	A	11/1999	Krieger	320/105	6,254,438	B1	7/2001	Gaunt	439/755
5,990,664	A	11/1999	Rahman	320/136	6,259,170	B1	7/2001	Limoge et al.	307/10.8
6,002,238	A	12/1999	Champlin	320/134	6,259,254	B1	7/2001	Klang	324/427
6,005,489	A	12/1999	Siegle et al.	340/825.69	6,262,563	B1	7/2001	Champlin	320/134
6,005,759	A	12/1999	Hart et al.	361/66	6,262,692	B1	7/2001	Babb	343/895
6,008,652	A	12/1999	Theofanopoulos et al.	324/434	6,263,268	B1 *	7/2001	Nathanson	G07C 5/085
6,009,369	A	12/1999	Boisvert et al.	701/99					340/870.01
6,016,047	A	1/2000	Notten et al.	320/137	6,263,322	B1 *	7/2001	Kirkevold	G06Q 30/0283
6,031,354	A	2/2000	Wiley et al.	320/116					705/400
6,031,368	A	2/2000	Klippel et al.	324/133	6,271,643	B1	8/2001	Becker et al.	320/112
6,037,745	A	3/2000	Koike et al.	320/104	6,271,748	B1	8/2001	Derbyshire et al.	340/442
6,037,749	A	3/2000	Parsonage	320/132	6,272,387	B1	8/2001	Yoon	700/83
6,037,751	A	3/2000	Klang	320/160	6,275,008	B1	8/2001	Arai et al.	320/132
6,037,777	A	3/2000	Champlin	324/430	6,285,191	B1	9/2001	Gollomp et al.	324/427
6,037,778	A	3/2000	Makhija	324/433	6,294,896	B1	9/2001	Champlin	320/134
6,046,514	A	4/2000	Rouillard et al.	307/77	6,294,897	B1	9/2001	Champlin	320/153
6,051,976	A	4/2000	Bertness	324/426	6,304,087	B1	10/2001	Bertness	324/426
6,055,468	A	4/2000	Kaman et al.	701/29	6,307,349	B1	10/2001	Koenck et al.	320/112
6,061,638	A	5/2000	Joyce	702/63	6,310,481	B2	10/2001	Bertness	324/430
6,064,372	A	5/2000	Kahkoska	345/173	6,313,607	B1	11/2001	Champlin	320/132
6,072,299	A	6/2000	Kurle et al.	320/112	6,313,608	B1	11/2001	Varghese et al.	320/132
6,072,300	A	6/2000	Tsuji	320/116	6,316,914	B1	11/2001	Bertness	320/134
6,075,339	A	6/2000	Reipur et al.	320/110	6,320,351	B1	11/2001	Ng et al.	320/104
6,081,098	A	6/2000	Bertness et al.	320/134	6,323,650	B1	11/2001	Bertness et al.	324/426
6,081,109	A	6/2000	Seymour et al.	324/127	6,324,042	B1	11/2001	Andrews	361/93.2
6,081,154	A	6/2000	Ezell et al.	327/540	6,329,793	B1	12/2001	Bertness et al.	320/132
6,087,815	A	7/2000	Pfeifer et al.	323/282	6,331,762	B1	12/2001	Bertness	320/134
					6,332,113	B1	12/2001	Bertness	702/63
					6,346,795	B2	2/2002	Haraguchi et al.	320/136
					6,347,958	B1	2/2002	Tsai	439/488
					6,351,102	B1	2/2002	Troy	320/139

(56)

References Cited

U.S. PATENT DOCUMENTS

6,356,042 B1	3/2002	Kahlon et al.	307/10.6	6,736,941 B2	5/2004	Oku et al.	701/31.4
6,356,083 B1	3/2002	Ying	324/426	6,737,831 B2	5/2004	Champlin	230/68
6,359,441 B1	3/2002	Bertness	324/426	6,738,697 B2	5/2004	Breed	320/132
6,359,442 B1	3/2002	Henningson et al.	324/426	6,740,990 B2	5/2004	Tozuka et al.	701/29
6,363,303 B1	3/2002	Bertness	701/29	6,744,149 B1	6/2004	Karuppana et al.	307/9.1
RE37,677 E	4/2002	Irie	315/83	6,745,153 B2	6/2004	White et al.	307/31
6,377,031 B1	4/2002	Karuppana et al.	323/220	6,759,849 B2	7/2004	Bertness	702/184
6,384,608 B1	5/2002	Namaky	324/430	6,771,073 B2	8/2004	Henningson et al.	324/426
6,388,448 B1	5/2002	Cervas	324/426	6,777,945 B2	8/2004	Roberts et al.	324/426
6,389,337 B1 *	5/2002	Kolls	B60R 25/04 340/439	6,781,344 B1	8/2004	Hedegor et al.	320/106
6,392,414 B2	5/2002	Bertness	324/429	6,781,382 B2	8/2004	Johnson	324/426
6,396,278 B1	5/2002	Makhija	324/402	6,784,635 B2	8/2004	Larson	320/104
6,407,554 B1	6/2002	Godau et al.	324/503	6,784,637 B2	8/2004	Raichle et al.	320/107
6,411,098 B1	6/2002	Laletin	324/436	6,788,025 B2	9/2004	Bertness et al.	320/104
6,417,669 B1	7/2002	Champlin	324/426	6,795,782 B2	9/2004	Bertness et al.	702/63
6,420,852 B1	7/2002	Sato	320/134	6,796,841 B1	9/2004	Cheng et al.	439/620.3
6,424,157 B1	7/2002	Gollomp et al.	324/430	6,805,090 B2	10/2004	Bertness et al.	123/198
6,424,158 B2	7/2002	Klang	324/433	6,806,716 B2	10/2004	Bertness et al.	324/426
6,433,512 B1	8/2002	Birkler et al.	320/132	6,825,669 B2	11/2004	Raichle et al.	324/426
6,437,957 B1	8/2002	Karuppana et al.	361/78	6,832,141 B2 *	12/2004	Skeen	G07C 5/008 340/439
6,441,585 B1	8/2002	Bertness	320/132	6,842,707 B2	1/2005	Raichle et al.	702/62
6,445,158 B1	9/2002	Bertness et al.	320/104	6,845,279 B1	1/2005	Gilmore et al.	700/115
6,448,778 B1	9/2002	Rankin	324/503	6,850,037 B2	2/2005	Bertness	320/132
6,449,726 B1	9/2002	Smith	713/340	6,856,162 B1	2/2005	Greatorex et al.	324/764.01
6,456,036 B1	9/2002	Thandiwe	320/106	6,856,972 B1	2/2005	Yun et al.	705/36 R
6,456,045 B1	9/2002	Troy et al.	320/139	6,871,151 B2	3/2005	Bertness	702/63
6,465,908 B1	10/2002	Karuppana et al.	307/31	6,885,195 B2	4/2005	Bertness	324/426
6,466,025 B1	10/2002	Klang	324/429	6,888,468 B2	5/2005	Bertness	340/636.15
6,466,026 B1	10/2002	Champlin	324/430	6,891,378 B2	5/2005	Bertness et al.	324/426
6,469,511 B1	10/2002	Vonderhaar et al.	324/425	6,904,796 B2	6/2005	Pacsai et al.	73/146.8
6,473,659 B1 *	10/2002	Shah	G06F 11/2242 382/141	6,906,522 B2	6/2005	Bertness et al.	324/426
6,477,478 B1	11/2002	Jones et al.	702/102	6,906,523 B2	6/2005	Bertness et al.	324/426
6,495,990 B2	12/2002	Champlin	320/132	6,906,624 B2	6/2005	McClelland et al.	340/442
6,497,209 B1	12/2002	Karuppana et al.	123/179.3	6,909,287 B2	6/2005	Bertness	324/427
6,500,025 B1	12/2002	Moenkhaus et al.	439/502	6,909,356 B2	6/2005	Brown et al.	340/3.2
6,505,507 B1	1/2003	Imao	73/146.5	6,911,825 B2	6/2005	Namaky	324/426
6,507,196 B2	1/2003	Thomsen et al.	324/436	6,913,483 B2	7/2005	Restaino et al.	439/504
6,526,361 B1	2/2003	Jones et al.	702/63	6,914,413 B2	7/2005	Bertness et al.	320/104
6,529,723 B1	3/2003	Bentley	455/405	6,919,725 B2	7/2005	Bertness et al.	324/433
6,531,848 B1	3/2003	Chitsazan et al.	320/153	6,930,485 B2	8/2005	Bertness et al.	324/426
6,532,425 B1	3/2003	Boost et al.	702/63	6,933,727 B2	8/2005	Bertness et al.	324/426
6,533,316 B2	3/2003	Breed et al.	280/735	6,941,234 B2	9/2005	Bertness et al.	702/63
6,534,992 B2	3/2003	Meissner et al.	324/426	6,957,133 B1 *	10/2005	Hunt	B60R 25/102 701/32.4
6,534,993 B2	3/2003	Bertness	324/433	6,967,484 B2	11/2005	Bertness	324/426
6,536,536 B1	3/2003	Gass et al.	173/2	6,972,662 B1	12/2005	Ohkawa et al.	340/10.1
6,544,078 B2	4/2003	Palmisano et al.	439/762	6,983,212 B2	1/2006	Burns	702/63
6,545,599 B2	4/2003	Derbyshire et al.	340/442	6,993,421 B2 *	1/2006	Pillar	A62C 27/00 701/29.4
6,556,019 B2	4/2003	Bertness	324/426	6,998,847 B2	2/2006	Bertness et al.	324/426
6,566,883 B1	5/2003	Vonderhaar et al.	324/426	7,003,410 B2	2/2006	Bertness et al.	702/63
6,570,385 B1	5/2003	Roberts et al.	324/378	7,003,411 B2	2/2006	Bertness	702/63
6,577,107 B2	6/2003	Kechmire	320/139	7,012,433 B2	3/2006	Smith et al.	324/426
6,586,941 B2	7/2003	Bertness et al.	324/426	7,015,674 B2	3/2006	Vonderhaar	320/103
6,597,150 B1	7/2003	Bertness et al.	320/104	7,029,338 B1	4/2006	Orange et al.	439/755
6,599,243 B2	7/2003	Woltermann et al.	600/300	7,034,541 B2	4/2006	Bertness et al.	324/426
6,600,815 B1	7/2003	Walding	379/93.07	7,039,533 B2	5/2006	Bertness et al.	702/63
6,611,740 B2	8/2003	Lowrey et al.	701/29	7,042,346 B2	5/2006	Paulsen	340/438
6,614,349 B1	9/2003	Proctor et al.	340/572.1	7,058,525 B2	6/2006	Bertness et al.	702/63
6,618,644 B2	9/2003	Bean	700/231	7,069,979 B2	7/2006	Tobias	165/104.33
6,621,272 B2	9/2003	Champlin	324/426	7,081,755 B2	7/2006	Klang et al.	324/426
6,623,314 B1	9/2003	Cox et al.	439/759	7,089,127 B2	8/2006	Thibedeau et al.	702/63
6,624,635 B1	9/2003	Lui	324/426	7,098,666 B2	8/2006	Patino	324/433
6,628,011 B2	9/2003	Droppo et al.	307/43	7,102,556 B2	9/2006	White	341/141
6,629,054 B2	9/2003	Makhija et al.	702/113	7,106,070 B2	9/2006	Bertness et al.	324/538
6,633,165 B2	10/2003	Bertness	324/426	7,116,109 B2	10/2006	Klang	324/426
6,635,974 B1	10/2003	Karuppana et al.	307/140	7,119,686 B2	10/2006	Bertness et al.	340/572.1
6,636,790 B1 *	10/2003	Lightner	G01M 15/102 701/31.4	7,120,488 B2	10/2006	Nova et al.	600/2
6,667,624 B1	12/2003	Raichle et al.	324/522	7,126,341 B2	10/2006	Bertness et al.	324/426
6,679,212 B2	1/2004	Kelling	123/179.28	7,129,706 B2	10/2006	Kalley	324/426
6,686,542 B2	2/2004	Zhang	174/74	7,154,276 B2	12/2006	Bertness	324/503
6,696,819 B2	2/2004	Bertness	320/134	7,170,393 B2	1/2007	Martin	340/10.1
6,707,303 B2	3/2004	Bertness et al.	324/426	7,177,925 B2	2/2007	Carcido et al.	709/223
6,732,031 B1 *	5/2004	Lightner	G01M 15/102	7,182,147 B2	2/2007	Cutler et al.	173/1
				7,184,866 B2 *	2/2007	Squires	A62C 27/00 340/426.15
				7,184,905 B2	2/2007	Stefan	702/63

(56)

References Cited

U.S. PATENT DOCUMENTS

7,198,510 B2	4/2007	Bertness	439/500	2001/0035737 A1	11/2001	Nakanishi et al.	320/122
7,200,424 B2	4/2007	Tischer et al.	455/567	2001/0048215 A1	12/2001	Breed et al.	280/728.1
7,202,636 B2	4/2007	Reynolds et al.	320/166	2002/0004694 A1	1/2002	McLeod	701/29
7,208,914 B2	4/2007	Klang	320/132	2002/0007237 A1*	1/2002	Phung	G05B 23/0216
7,209,850 B2	4/2007	Brott et al.	324/426				701/31.4
7,209,860 B2*	4/2007	Trsar	G06F 11/2257				702/63
			701/31.4				324/677
7,212,887 B2	5/2007	Shah et al.	700/276	2002/0010558 A1	1/2002	Bertness et al.	280/735
7,219,023 B2	5/2007	Banke et al.	702/58	2002/0021135 A1	2/2002	Li et al.	324/427
7,233,128 B2	6/2007	Brost et al.	320/132	2002/0027346 A1	3/2002	Breed et al.	324/430
7,235,977 B2	6/2007	Koran et al.	324/426	2002/0030495 A1	3/2002	Kechmire	320/106
7,246,015 B2	7/2007	Bertness et al.	702/63	2002/0036504 A1	3/2002	Troy et al.	340/442
7,272,519 B2	9/2007	Lesesky et al.	702/63	2002/0041175 A1	4/2002	Lauper et al.	324/426
7,287,001 B1	10/2007	Falls et al.	705/22	2002/0044050 A1	4/2002	Derbyshire et al.	73/116
7,295,936 B2	11/2007	Bertness et al.	702/63	2002/0047711 A1	4/2002	Bertness et al.	235/382
7,319,304 B2	1/2008	Veloo et al.	320/134	2002/0050163 A1	5/2002	Makhija et al.	702/63
7,339,477 B2	3/2008	Puzio et al.	340/572.1	2002/0074398 A1	6/2002	Lancos et al.	340/573.1
7,363,175 B2	4/2008	Bertness et al.	702/63	2002/0116140 A1	8/2002	Rider	324/426
7,376,497 B2*	5/2008	Chen	C05F 11/08	2002/0118111 A1	8/2002	Brown et al.	705/400
			701/31.6	2002/0121901 A1	9/2002	Hoffman	324/426
7,398,176 B2	7/2008	Bertness	702/140	2002/0128985 A1*	9/2002	Greenwald	G06Q 30/02
7,408,358 B2	8/2008	Knopf	324/426				324/426
7,425,833 B2	9/2008	Bertness et al.	324/426	2002/0130665 A1	9/2002	Bertness et al.	702/63
7,446,536 B2	11/2008	Bertness	324/426	2002/0171428 A1	11/2002	Bertness	348/362
7,453,238 B2	11/2008	Melichar	320/132	2002/0176010 A1	11/2002	Wallach et al.	324/503
7,479,763 B2	1/2009	Bertness	320/134	2003/0006779 A1	1/2003	Youval	701/29
7,498,767 B2	3/2009	Brown et al.	320/107	2003/0009270 A1	1/2003	Breed	439/762
7,501,795 B2	3/2009	Bertness et al.	320/134	2003/0017753 A1	1/2003	Palmisano et al.	324/427
7,505,856 B2	3/2009	Restaino et al.	702/63	2003/0025481 A1	2/2003	Bertness	704/275
7,545,146 B2	6/2009	Klang et al.	324/426	2003/0036909 A1	2/2003	Kato	702/57
7,557,586 B1	7/2009	Vonderhaar et al.	324/437	2003/0040873 A1	2/2003	Lesesky et al.	G06Q 90/00
7,590,476 B2*	9/2009	Shumate	G05B 23/0275	2003/0060953 A1*	3/2003	Chen	701/31.4
			701/31.6				702/63
7,592,776 B2	9/2009	Tsukamoto et al.	320/136	2003/0078743 A1	4/2003	Bertness et al.	702/63
7,595,643 B2	9/2009	Klang	324/426	2003/0088375 A1	5/2003	Bertness et al.	429/90
7,598,699 B2	10/2009	Restaino et al.	320/105	2003/0124417 A1	7/2003	Bertness et al.	324/426
7,598,743 B2	10/2009	Bertness	324/426	2003/0128011 A1	7/2003	Bertness et al.	320/132
7,598,744 B2	10/2009	Bertness et al.	324/426	2003/0128036 A1	7/2003	Henningson et al.	320/132
7,619,417 B2	11/2009	Klang	324/427	2003/0137277 A1	7/2003	Mori et al.	320/132
7,642,786 B2	1/2010	Philbrook	324/426	2003/0137277 A1	7/2003	Mori et al.	320/132
7,642,787 B2	1/2010	Bertness et al.	324/426	2003/0169018 A1	9/2003	Berels et al.	320/132
7,656,162 B2	2/2010	Vonderhaar et al.	324/426	2003/0169019 A1	9/2003	Oosaki	H04L 69/329
7,657,386 B2	2/2010	Thibedeau et al.	702/63	2003/0171111 A1*	9/2003	Clark	455/414.1
7,667,437 B2	2/2010	Johnson et al.	320/150				714/42
7,679,325 B2	3/2010	Seo	20/116	2003/0177417 A1*	9/2003	Malhotra et al.	320/156
7,684,908 B1*	3/2010	Ogilvie	G07C 5/0808	2003/0184262 A1	10/2003	Makhija	324/426
			701/29.6	2003/0184306 A1	10/2003	Bertness et al.	701/29
7,688,074 B2	3/2010	Cox et al.	324/426	2003/0187556 A1	10/2003	Suzuki	431/196
7,698,179 B2	4/2010	Leung et al.	705/28	2003/0194672 A1	10/2003	Roberts et al.	324/426
7,705,602 B2	4/2010	Bertness	324/426	2003/0197512 A1	10/2003	Miller et al.	600/300
7,706,991 B2	4/2010	Bertness et al.	702/63	2003/0212311 A1	11/2003	Nova et al.	340/445
7,710,119 B2	5/2010	Bertness	324/426	2003/0214395 A1	11/2003	Flowerday et al.	703/14
7,723,993 B2	5/2010	Klang	324/431	2003/0236656 A1	12/2003	Dougherty	235/462.01
7,728,556 B2	6/2010	Yano et al.	320/134	2004/0000590 A1	1/2004	Raichle et al.	320/107
7,728,597 B2	6/2010	Bertness	324/426	2004/0000891 A1	1/2004	Raichle et al.	320/135
7,751,953 B2	7/2010	Namaky	701/33.2	2004/0000893 A1	1/2004	Raichle et al.	324/426
7,772,850 B2	8/2010	Bertness	324/426	2004/0000913 A1	1/2004	Raichle et al.	702/63
7,774,130 B2*	8/2010	Pepper	B60W 40/12	2004/0000915 A1	1/2004	Raichle et al.	702/188
			340/439	2004/0002824 A1	1/2004	Raichle et al.	324/426
7,774,151 B2	8/2010	Bertness	702/63	2004/0002825 A1	1/2004	Raichle et al.	702/63
7,777,612 B2	8/2010	Sampson et al.	340/426.1	2004/0002836 A1	1/2004	Raichle et al.	702/188
7,791,348 B2	9/2010	Brown et al.	324/426	2004/0032264 A1	2/2004	Schoch	324/426
7,808,375 B2	10/2010	Bertness et al.	340/455	2004/0036443 A1	2/2004	Bertness	320/109
7,848,857 B2*	12/2010	Nasr	B60K 6/46	2004/0044452 A1	3/2004	Bauer et al.	703/33
			290/40 B	2004/0044454 A1*	3/2004	Ross	B60R 16/0231
			235/376				701/36
7,883,002 B2	2/2011	Jin et al.	235/376	2004/0049361 A1	3/2004	Hamdan et al.	702/115
7,902,990 B2	3/2011	Delmonico et al.	340/636.1	2004/0051532 A1	3/2004	Smith et al.	324/426
7,924,015 B2	4/2011	Bertness	324/427	2004/0051533 A1	3/2004	Namaky	324/426
7,940,053 B2	5/2011	Brown et al.	324/426	2004/0051534 A1	3/2004	Kobayashi et al.	324/429
7,990,155 B2	8/2011	Henningson	324/429	2004/0054503 A1	3/2004	Namaky	702/182
7,999,505 B2	8/2011	Bertness	320/104	2004/0064225 A1*	4/2004	Jammu	G06Q 10/06
8,024,083 B2*	9/2011	Chenn	G07C 5/085				701/29.4
			701/2	2004/0088087 A1*	5/2004	Fukushima	B60R 16/0232
8,164,343 B2	4/2012	Bertness	324/503				701/29.6
8,306,690 B2	11/2012	Bertness	701/34.4	2004/0113588 A1	6/2004	Mikuriya et al.	320/128
				2004/0145342 A1	7/2004	Lyon	320/108
				2004/0164706 A1	8/2004	Osborne	320/116
				2004/0172177 A1*	9/2004	Nagai	G07C 5/085
							701/33.4
				2004/0178185 A1	9/2004	Yoshikawa et al.	219/270
				2004/0189309 A1	9/2004	Bertness et al.	324/426

U.S. PATENT DOCUMENTS

2004/0199343	A1	10/2004	Cardinal et al.	702/63
2004/0207367	A1	10/2004	Taniguchi et al.	320/149
2004/0221641	A1 *	11/2004	Moritsugu	G01N 33/007 73/23.31
2004/0227523	A1 *	11/2004	Namaky	H04L 67/125 324/537
2004/0239332	A1	12/2004	Mackel et al.	324/426
2004/0251876	A1	12/2004	Bertness	320/136
2005/0007068	A1	1/2005	Johnson et al.	320/110
2005/0009122	A1	1/2005	Whelan et al.	435/7.32
2005/0017726	A1	1/2005	Koran et al.	324/433
2005/0017952	A1	1/2005	Hsi	345/169
2005/0021197	A1 *	1/2005	Zimmerman	G06Q 10/10 701/31.4
2005/0021294	A1 *	1/2005	Trsar	G06F 11/2257 702/183
2005/0025299	A1	2/2005	Tischer et al.	379/199
2005/0043868	A1	2/2005	Mitcham	701/29
2005/0057256	A1	3/2005	Bertness	324/426
2005/0060070	A1 *	3/2005	Kapolka	G07C 5/008 701/31.4
2005/0073314	A1	4/2005	Bertness et al.	324/433
2005/0076381	A1	4/2005	Gross	725/107
2005/0096809	A1 *	5/2005	Skeen	G07C 5/008 701/31.4
2005/0102073	A1	5/2005	Ingram	701/29
2005/0119809	A1 *	6/2005	Chen	G06Q 90/00 701/33.5
2005/0128083	A1	6/2005	Puzio et al.	340/572.1
2005/0128902	A1	6/2005	Tsai	369/44.32
2005/0134282	A1	6/2005	Averbuch	324/426
2005/0143882	A1 *	6/2005	Umezawa	G07C 5/085 701/31.4
2005/0159847	A1	7/2005	Shah et al.	700/276
2005/0162172	A1	7/2005	Bertness	324/426
2005/0168226	A1	8/2005	Quint et al.	324/426
2005/0173142	A1	8/2005	Cutler et al.	173/181
2005/0182536	A1	8/2005	Doyle et al.	701/29
2005/0212521	A1 *	9/2005	Bertness	G01R 1/06 324/426
2005/0213874	A1	9/2005	Kline	385/15
2005/0218902	A1 *	10/2005	Restaino	G01R 19/16542 324/433
2005/0231205	A1 *	10/2005	Bertness	G01R 31/3627 324/426
2005/0254106	A9	11/2005	Silverbrook et al.	358/539
2005/0256617	A1	11/2005	Cawthorne et al.	701/22
2005/0258241	A1	11/2005	McNutt et al.	235/385
2006/0012330	A1	1/2006	Okumura et al.	320/103
2006/0017447	A1	1/2006	Bertness	324/538
2006/0026017	A1 *	2/2006	Walker	H04L 63/302 701/31.4
2006/0030980	A1	2/2006	St. Denis	701/29
2006/0043976	A1	3/2006	Gervais	324/508
2006/0079203	A1 *	4/2006	Nicolini	H04M 3/51 455/411
2006/0089767	A1	4/2006	Sowa	701/29
2006/0095230	A1 *	5/2006	Grier	G05B 23/0216 702/183
2006/0152224	A1	7/2006	Kim et al.	324/430
2006/0155439	A1 *	7/2006	Slawinski	G07C 5/0858 701/33.4
2006/0161313	A1 *	7/2006	Rogers	G60F 3/0481 701/1
2006/0161390	A1 *	7/2006	Namaky	G07C 5/0808 702/183
2006/0217914	A1	9/2006	Bertness	702/113
2006/0244457	A1	11/2006	Henningson et al.	324/426
2006/0282323	A1	12/2006	Walker et al.	705/14
2007/0024460	A1	2/2007	Clark	340/663
2007/0026916	A1	2/2007	Juds et al.	463/1
2007/0046261	A1	3/2007	Porebski	320/132
2007/0088472	A1 *	4/2007	Ganzhorn, Jr.	G01M 15/102 701/31.4
2007/0108942	A1	5/2007	Johnson et al.	320/112

2007/0159177	A1	7/2007	Bertness et al.	324/426
2007/0182576	A1	8/2007	Proska et al.	340/636.1
2007/0194791	A1	8/2007	Huang	324/430
2007/0194793	A1	8/2007	Bertness	324/503
2007/0205983	A1	9/2007	Naimo	345/160
2007/0259256	A1	11/2007	Le Canut et al.	429/90
2008/0036421	A1	2/2008	Seo et al.	320/132
2008/0059014	A1 *	3/2008	Nasr	B60K 6/46 701/22
2008/0064559	A1 *	3/2008	Cawthorne	B60W 10/06 477/5
2008/0086246	A1 *	4/2008	Bolt	G01R 31/007 701/31.4
2008/0094068	A1	4/2008	Scott	324/426
2008/0103656	A1 *	5/2008	Lipscomb	G07C 5/008 701/33.4
2008/0169818	A1	7/2008	Lesesky et al.	324/426
2008/0303528	A1	12/2008	Kim	324/430
2008/0303529	A1	12/2008	Nakamura et al.	324/433
2008/0315830	A1 *	12/2008	Bertness	G01R 31/3648 320/104
2009/0006476	A1 *	1/2009	Andreasen	G06Q 50/30
2009/0024266	A1 *	1/2009	Bertness	G01R 31/007 701/22
2009/0085571	A1	4/2009	Bertness	324/426
2009/0146800	A1	6/2009	Grimlund et al.	340/505
2009/0198372	A1	8/2009	Hammerslag	700/226
2009/0203247	A1 *	8/2009	Fifelski	H01R 13/6273 439/345
2009/0247020	A1	10/2009	Gathman et al.	439/759
2009/0276115	A1 *	11/2009	Chen	G07C 5/008 701/29.6
2010/0023198	A1 *	1/2010	Hamilton	B60R 16/03 701/31.4
2010/0145780	A1	6/2010	Nishikawa et al.	705/14.11
2010/0314950	A1	12/2010	Rutkowski et al.	307/125
2011/0004427	A1	1/2011	Gorbold et al.	702/63
2011/0015815	A1 *	1/2011	Bertness	B60L 1/003 701/22
2011/0273181	A1	11/2011	Park et al.	324/429
2012/0046824	A1 *	2/2012	Ruther	B60R 16/0315 701/31.5
2012/0274904	A1	3/2012	Rutkowski et al.	320/112
2012/0256494	A1	10/2012	Kesler	307/104
2013/0158782	A1	6/2013	Bertness et al.	701/34.4
2013/0311124	A1	11/2013	Van Bremen	702/104
2014/0002094	A1	1/2014	Champlin	324/426

DE	29 26 716	B1	1/1981
DE	196 38 324		9/1996
DE	10 2008 036 595	A1	2/2010
EP	0 022 450	A1	1/1981
EP	0 391 694	A2	4/1990
EP	0 476 405	A1	9/1991
EP	0 637 754	A1	2/1995
EP	0 772 056	A1	5/1997
EP	0 982 159	A2	3/2000
EP	1 810 869	A1	11/2004
EP	1 807 710	B1	7/2007
EP	1 807 710		1/2010
FR	2 749 397		12/1997
GB	2 029 586		3/1980
GB	2 088 159	A	6/1982
GB	2 246 916	A	10/1990
GB	2 275 783	A	7/1994
GB	2 387 235	A	10/2003
JP	59-17892		1/1984
JP	59-17893		1/1984
JP	59017894		1/1984
JP	59215674		12/1984
JP	60225078		11/1985
JP	62-180284		8/1987
JP	63027776		2/1988
JP	03274479		12/1991
JP	03282276		12/1991
JP	4-8636		1/1992
JP	04095788		3/1992

(56)

References Cited

FOREIGN PATENT DOCUMENTS

JP	04131779	5/1992
JP	04372536	12/1992
JP	05211724 A	8/1993
JP	5216550	8/1993
JP	7-128414	5/1995
JP	09061505	3/1997
JP	10056744	2/1998
JP	10232273	9/1998
JP	11103503 A	4/1999
JP	11-150809	6/1999
JP	11-271409	10/1999
JP	2001057711 A	2/2001
JP	2003-346909	12/2003
JP	2006331976 A	12/2006
JP	2009-244166	10/2009
RU	2089015 C1	8/1997
WO	WO 93/22666	11/1993
WO	WO 94/05069	3/1994
WO	WO 96/01456	1/1996
WO	WO 96/06747	3/1996
WO	WO 96/28846	9/1996
WO	WO 97/01103	1/1997
WO	WO 97/44652	11/1997
WO	WO 98/04910	2/1998
WO	WO 98/21132	5/1998
WO	WO 98/58270	12/1998
WO	WO 99/23738	5/1999
WO	WO 99/56121	11/1999
WO	WO 00/16083	3/2000
WO	WO 00/62049	10/2000
WO	WO 00/67359	11/2000
WO	WO 01/59443	2/2001
WO	WO 01/16614	3/2001
WO	WO 01/16615	3/2001
WO	WO 01/51947	7/2001
WO	WO 03/047064 A3	6/2003
WO	WO 03/076960 A1	9/2003
WO	WO 2004/047215 A1	6/2004
WO	WO 2010/007681	1/2010
WO	WO 2011/153419	12/2011

OTHER PUBLICATIONS

"Battery Impedance", by E. Willihnganz et al., *Electrical Engineering*, Sep. 1959, pp. 922-925.

"Determining the End of Battery Life", by S. DeBardelaben, *IEEE*, 1986, pp. 365-368.

"A Look at the Impedance of a Cell", by S. DeBardelaben, *IEEE*, 1988, pp. 394-397.

"The Impedance of Electrical Storage Cells", by N.A. Hampson et al., *Journal of Applied Electrochemistry*, 1980, pp. 3-11.

"A Package for Impedance/Admittance Data Analysis", by B. Boukamp, *Solid State Ionics*, 1986, pp. 136-140.

"Precision of Impedance Spectroscopy Estimates of Bulk, Reaction Rate, and Diffusion Parameters", by J. Macdonald et al., *J. Electroanal. Chem.*, 1991, pp. 1-11.

Internal Resistance: Harbinger of Capacity of Loss in Starved Electrolyte Sealed Lead Acid Batteries, by Vaccaro, F.J. et al., *AT&T Bell Laboratories*, 1987 IEEE, Ch. 2477, pp. 128,131.

IEEE Recommended Practice for Maintenance, Testings, and Replacement of Large Lead Storage Batteries for Generating Stations and Substations, *The Institute of Electrical and Electronics Engineers, Inc. ANSI/IEEE Std. 450-1987*, Mar. 9, 1987, pp. 7-15.

"Field and Laboratory Studies to Assess the State of Health of Valve-Regulated Lead Acid Batteries: Part I Conductance/Capacity Correlation Studies", by D. Feder et al., *IEEE*, Aug. 1992, pp. 218-233.

"JIS Japanese Industrial Standard—Lead Acid Batteries for Automobiles", *Japanese Standards Association UDC*, 621.335.2:629.113.006, Nov. 1995.

"Performance of Dry Cells", by C. Hambuechen, Preprint of *Am. Electrochem. Soc.*, Apr. 18-20, 1912, paper No. 19, pp. 1-5.

"A Bridge for Measuring Storage Battery Resistance", by E. Willihnganz, *The Electrochemical Society*, preprint 79-20, Apr. 1941, pp. 253-258.

National Semiconductor Corporation, "High Q Notch Filter", Mar. 1969, Linear Brief 5, Mar. 1969.

Burr-Brown Corporation, "Design a 60 Hz Notch Filter with the UAF42", Jan. 1994, AB-071, 1994.

National Semiconductor Corporation, "LMF90-4th-Order Elliptic Notch Filter", Dec. 1994, RRD-B30M115, Dec. 1994.

"Alligator Clips with Wire Penetrators" *J.S. Popper, Inc.* product information, downloaded from <http://www.jspopper.com/>, prior to Oct. 1, 2002.

"#12: LM78S40 Simple Switcher DC to DC Converter", *ITM e-Catalog*, downloaded from <http://www.pcbcafe.com>, prior to Oct. 1, 2002.

"Simple DC-DC Converts Allows Use of Single Battery", *Electronic Express*, downloaded from http://www.elexp.com/t_dc-dc.htm, prior to Oct. 1, 2002.

"DC-DC Converter Basics", *Power Designers*, downloaded from http://www.powderdesigners.com/InforWeb.design_center/articles/DGDC/converter.shtm, prior to Oct. 1, 2002.

"Notification of Transmittal of the International Search Report or the Declaration", PCT/US02/29461.

"Notification of Transmittal of the International Search Report or the Declaration", PCT/US03/07546.

"Notification of Transmittal of the International Search Report or the Declaration", PCT/US03/06577.

"Notification of Transmittal of the International Search Report or the Declaration", PCT/US03/07837.

"Improved Impedance Spectroscopy Technique for Status Determination of Production Li/SO₂ Batteries" Terrill Atwater et al., pp. 10-113, (1992).

"Notification of Transmittal of the International Search Report or the Declaration", PCT/US03/41561.

"Notification of Transmittal of the International Search Report or the Declaration", PCT/US03/27696.

"Programming Training Course, 62-000 Series Smart Engine Analyzer", Testproducts Division, Kalamazoo, Michigan, pp. 1-207, (1984).

"Operators Manual, Modular Computer Analyzer Model MCA 3000", Sun Electric Corporation, Crystal Lake, Illinois, pp. 1-1-14-13, (1991).

Supplementary European Search Report Communication for Appl. No. 99917402.2; Sep. 7, 2004.

"Dynamic modelling of lead/acid batteries using impedance spectroscopy for parameter identification", *Journal of Power Sources*, pp. 69-84, (1997).

Notification of Transmittal of the International Search Report for PCT/US03/30707.

"A review of impedance measurements for determination of the state-of-charge or state-of-health of secondary batteries", *Journal of Power Sources*, pp. 59-69, (1998).

"Search Report Under Section 17" for Great Britain Application No. GB0421447.4.

"Results of Discrete Frequency Imittance Spectroscopy (DFIS) Measurements of Lead Acid Batteries", by K.S. Champlin et al., *Proceedings of 23rd International Teleco Conference (INTELEC)*, published Oct. 2001, IEE, pp. 433-440.

"Examination Report" from the UK Patent Office for App. No. 0417678.0; Jan. 24, 2005.

Wikipedia Online Encyclopedia, Inductance, 2005, <http://en.wikipedia.org/wiki/inductance>, pp. 1-5, mutual Inductance, pp. 3,4.

"Professional BCS System Analyzer Battery-Charger-Starting", pp. 2-8, (2001).

Young Illustrated Encyclopedia Dictionary of Electronics, 1981, Parker Publishing Company, Inc., pp. 318-319.

"DSP Applications in Hybrid Electric Vehicle Powertrain", Miller et al., *Proceedings of the American Control Conference*, Sand Diego, CA, Jun. 1999; 2 ppg.

"Notification of Transmittal of the International Search Report and the Written Opinion of the International Searching Authority, or the Declaration" for PCT/US2008/008702 filed Jul. 2008; 15 pages.

"Notification Concerning Availability of the Publication of the International Application" for PCT/US2008/008702, filed Jul. 17, 2008; 24 pages.

(56)

References Cited**OTHER PUBLICATIONS**

"A Microprocessor-Based Control System for a Near-Term Electric Vehicle", Bimal K. Bose; IEEE Transactions on Industry Applications, vol. IA-17, No. 6, Nov./Dec. 1981; 0093-9994/81/1100-0626\$00.75 © 1981 IEEE, 6 pages.

"First Notice Informing the Applicant of the Communication of the International Application (to Designated Offices which do not apply the 30 Month Time Limit Under Article 22(1))" for PCT/US2008/008702 filed Jul. 17, 2008; one page.

"Notification of the Recording of a Change" for PCT/US2008/008702 filed Jul. 17, 2008; one page.

Examination Report under section 18(3) for corresponding Great Britain Application No. GB1000773.0, dated Feb. 6, 2012, 2 pages. Office Action from related U.S. Appl. No. 12/174,894, mailed on Apr. 27, 2011, 15 pages.

U.S. Appl. No. 60/387,912, filed Jun. 13, 2002 which is related to U.S. Pat. No. 7,089,127.

"Conductance Testing Compared to Traditional Methods of Evaluating the Capacity of Valve-Regulated Lead-Acid Batteries and Predicting State-of-Health", by D. Feder et al., May 1992, pp. 1-8; (13 total pgs.).

"Field and Laboratory Studies to Assess the State of Health of Valve-Regulated Lead Acid Batteries: Part I—Conductance/Capacity Correlation Studies", by D. Feder et al., Oct. 1992, pp. 1-15; (19 total pgs.).

"Field Application of Conductance Measurements Use to Ascertain Cell/Battery and Inter-Cell Connection State-of-Health in Electric Power Utility Applications", by M. Hlavac et al., Apr. 1993, pp. 1-14; (19 total pgs.).

"Conductance Testing of Standby Batteries in Signaling and Communications Applications for the Purpose of Evaluating Battery State-of-Health", by S. McShane, Apr. 1993, pp. 1-9; (14 total pgs.).

"Conductance Monitoring of Recombination Lead Acid Batteries", by B. Jones, May 1993, pp. 1-6; (11 total pgs.).

"Evaluating the State-of-Health of Lead Acid Flooded and Valve-Regulated Batteries: A Comparison of Conductance Testing vs. Traditional Methods", by M. Hlavac et al., Jun. 1993, pp. 1-15; (20 total pgs.).

"Updated State of Conductance/Capacity Correlation Studies to Determine the State-of-Health of Automotive SLI and Standby Lead Acid Batteries", by D. Feder et al., Sep. 1993, pp. 1-17; (22 total pgs.).

"Field and Laboratory Studies to Access the State-of-Health of Valve-Regulated Lead-Acid Battery Technologies Using Conductance Testing Part II—Further Conductance/Capacity Correlation Studies", by M. Hlavac et al., Sep. 1993, pp. 1-9; (14 total pgs.).

"Field Experience of Testing VRLA Batteries by Measuring Conductance", by M.W. Kniveton, May 1994, pp. 1-4; (9 total pgs.).

"Reducing the Cost of Maintaining VRLA Batteries in Telecom Applications", by M.W. Kniveton, Sep. 1994, pp. 1-5; (10 total pgs.).

"Analysis and Interpretation of Conductance Measurements used to Access the State-of-Health of Valve Regulated Lead Acid Batteries Part III: Analytical Techniques", by M. Hlavac, Nov. 1994, 9 pgs; (13 total pgs.).

"Testing 24 Volt Aircraft Batteries Using Midtronics Conductance Technology", by M. Hlavac et al., Jan. 1995, 9 pgs; (13 total pgs.).

"VRLA Battery Monitoring Using Conductance Technology Part IV: On-Line State-of-Health Monitoring and Thermal Runaway Detection/Prevention", by M. Hlavac et al., Oct. 1995, 9 pgs; (13 total pgs.).

"VRLA Battery Conductance Monitoring Part V: Strategies for VRLA Battery Testing and Monitoring in Telecom Operating Environments", by M. Hlavac et al., Oct. 1996, 9 pgs; (13 total pgs.).

"Midpoint Conductance Technology Used in Telecommunication Stationary Standby Battery Applications Part VI: Considerations for Deployment of Midpoint Conductance in Telecommunications Power Applications", by M. Troy et al., Oct. 1997, 9 pgs; (13 total pgs.).

"Impedance/Conductance Measurements as an Aid to Determining Replacement Strategies", M. Kniveton, Sep. 1998, pp. 297-301; (9 total pgs.).

"A Fundamentally New Approach to Battery Performance Analysis Using DFRA™/DTIST™ Technology", by K. Champlin et al., Sep. 2000, 8 pgs; (12 total pgs.).

"Battery State of Health Monitoring, Combining Conductance Technology With Other Measurement Parameters for Real-Time Battery Performance Analysis", by D. Cox et al., Mar. 2000, 6 pgs; (10 total pgs.).

Notification of Transmittal of the International Search Report and Written Opinion from PCT/US2011/039043, dated Jul. 26, 2012.

Notification of Transmittal of the International Search Report and Written Opinion from PCT/US2011/053886, dated Jul. 27, 2012.

Combined Search and Examination Report under Sections 17 and 18(3) for GB Application No. GB1216105.5, dated Sep. 21, 2012, 4 pages.

Office Action for U.S. Appl. No. 12/174,894, dated Nov. 8, 2011, 19 pgs.

Search Report and Written Opinion from PCT Application No. PCT/US2011/026608, dated Aug. 29, 2011, 9 pgs.

Search Report and Written Opinion from PCT Application No. PCT/US2011/038279, dated Sep. 16, 2011, 12 pgs.

Search Report and Written Opinion from PCT/US2011/047354, dated Nov. 11, 2011.

First Office Action (Notification of Reasons for Rejections) dated Dec. 3, 2013 in related Japanese Patent Appln. No. 2013-513370, 9 pgs, including English Translation.

"Field Evaluation of Honda's EV PLUS Battery Packs", by A. Paryani, IEEE AES Systems Magazine, Nov. 2000, pp. 21-24.

Official Action dated Jan. 22, 2014 in Korean patent application No. 10-2012-7033020, 2 pgs. including English Translation.

Official Action dated Feb. 20, 2014 in Korean patent application No. 10-2013-7004814, 6 pgs. including English Translation.

First Office Action for Chinese Patent Application No. 201180011597.4, dated May 6, 2014, 20 pages.

Office Action from Korean Application No. 10-2012-7033020, dated Jul. 29, 2014.

Office Action for Chinese Patent Application No. 201180038844.X, dated Jul. 1, 2014.

Office Action for Chinese Patent Application No. 201180030045.8, dated Jul. 21, 2014.

Office Action for German Patent Application No. 1120111030643 dated Aug. 28, 2014.

Office Action from Japanese Patent Application No. 2013-513370, dated Aug. 5, 2014.

Office Action from Japanese Patent Application No. 2013-531839, dated Jul. 8, 2014.

Office Action for U.S. Appl. No. 13/668,523, dated Apr. 21, 2015.

Office Action for U.S. Appl. No. 13/668,523, dated Jul. 30, 2014.

Office Action for U.S. Appl. No. 13/668,523, dated Oct. 23, 2013.

Office Action for German Patent Application No. 103 32 625.1, dated Nov. 7, 2014, 14 pages.

Office Action from Chinese Patent Application No. 201180038844.X, dated Dec. 8, 2014.

Office Action from CN Application No. 201180011597.4, dated Jan. 6, 2015.

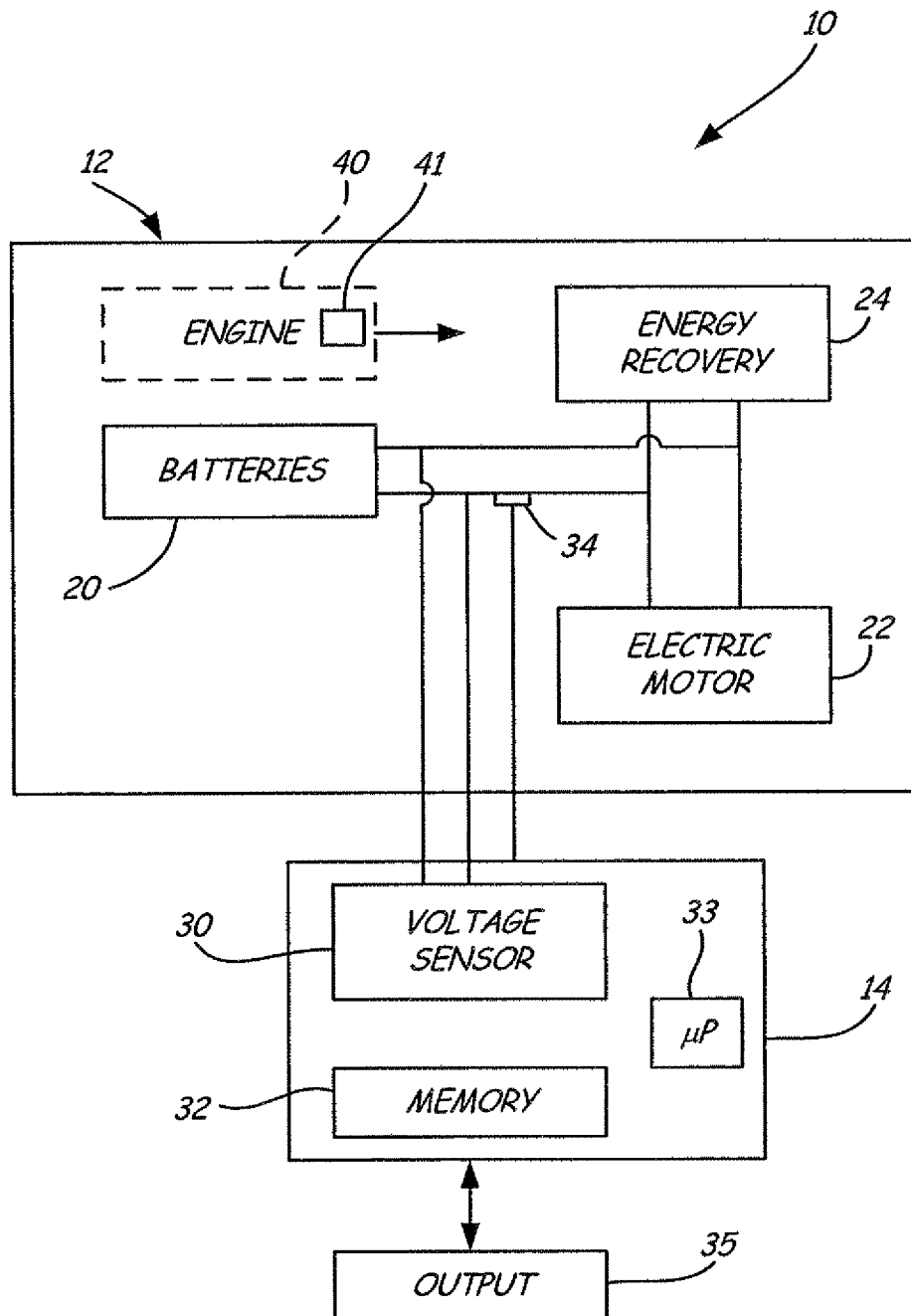
Office Action for Chinese Patent Application No. 201180030045.8, dated Mar. 24, 2015.

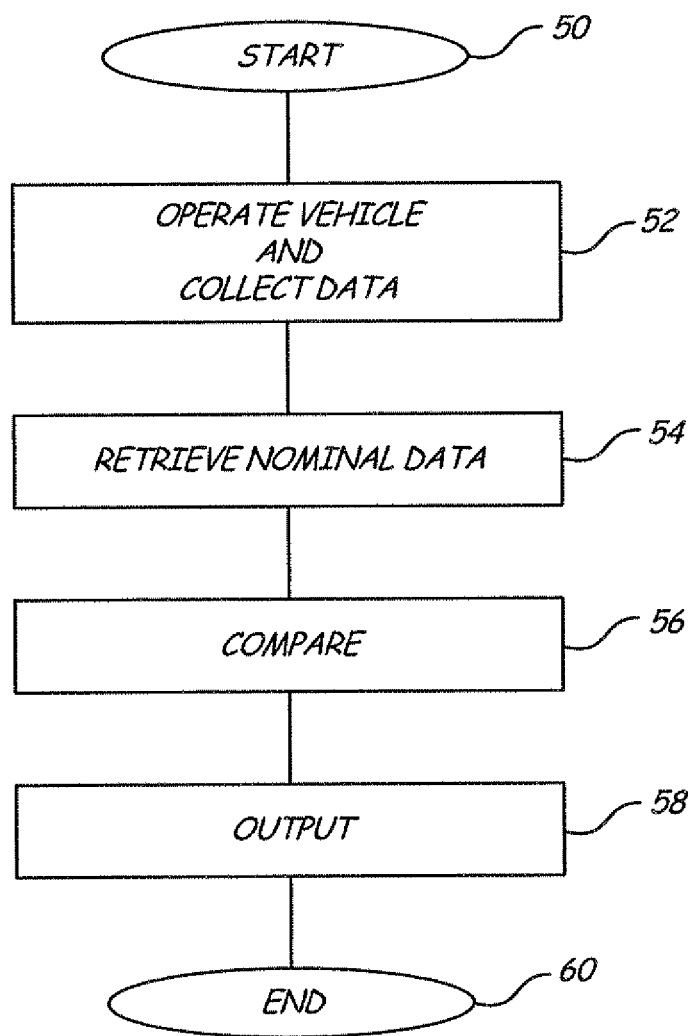
Office Action for Japanese Patent Application No. 2013-531839, dated Mar. 31, 2015.

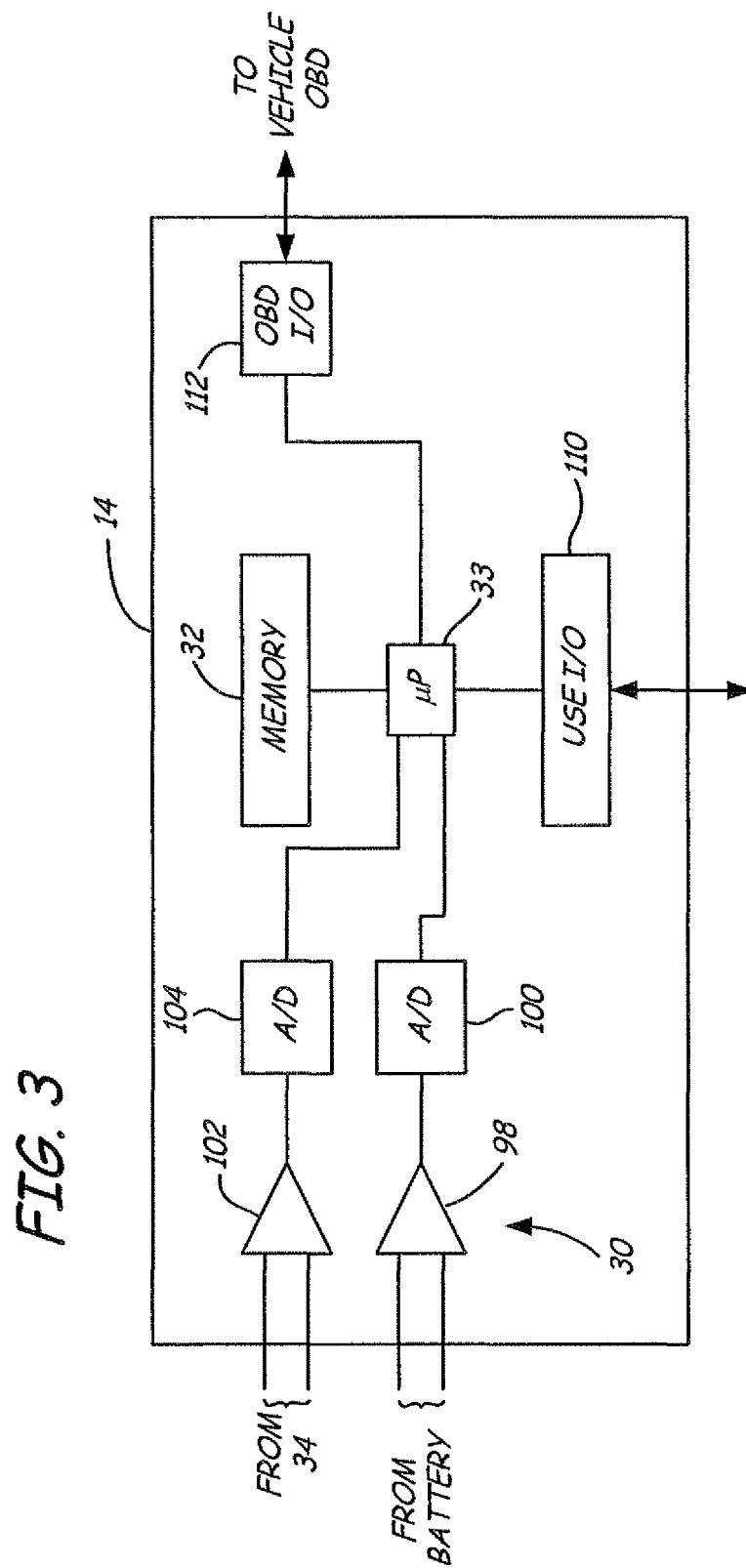
Office Action for Chinese Patent Application No. 201180038844.X, dated Jun. 8, 2015.

Notification of Transmittal of the International Search Report and Written Opinion from PCT/US2014/069661, dated Mar. 26, 2015.

* cited by examiner

**FIG. 1**

*FIG. 2*



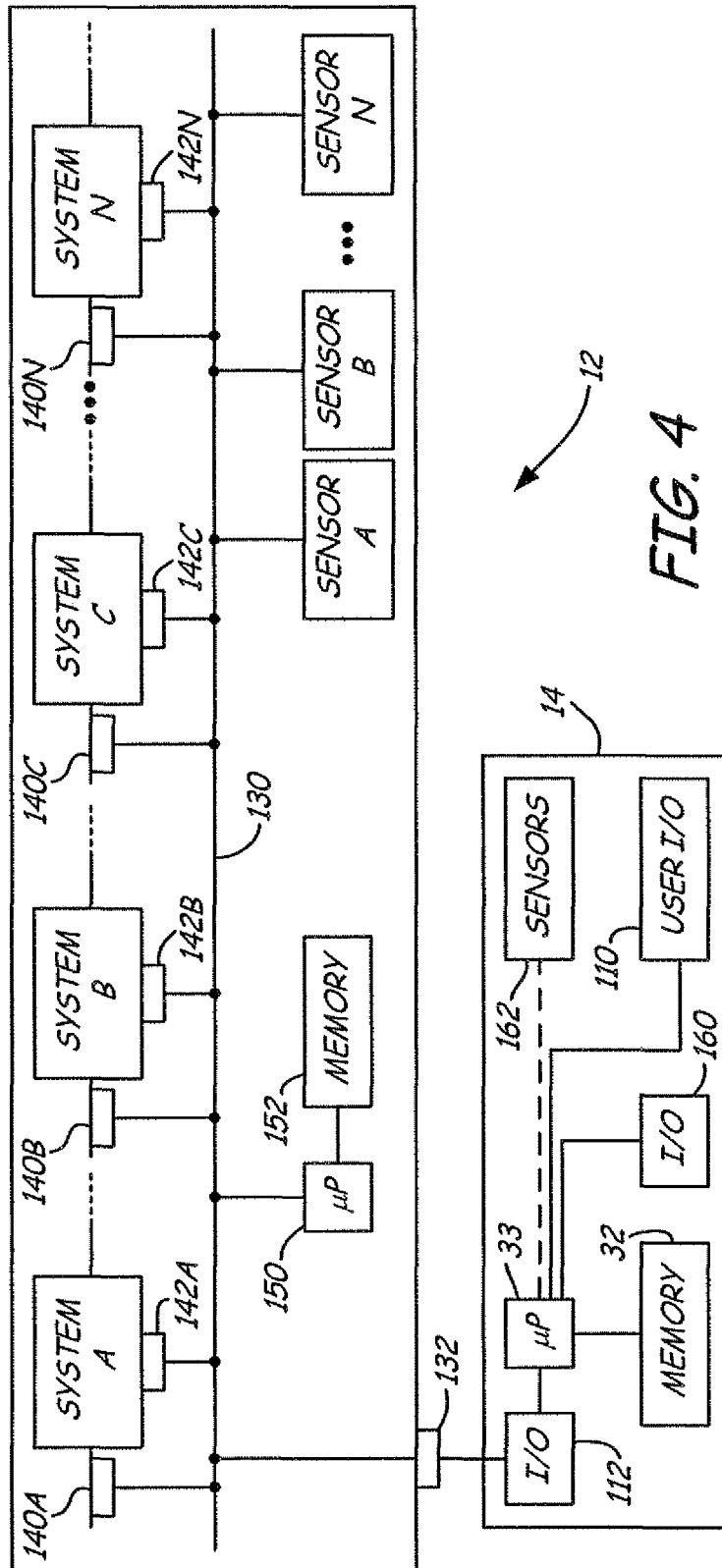


FIG. 4

**BATTERY TESTER FOR ELECTRIC
VEHICLE****CROSS-REFERENCE TO RELATED
APPLICATION**

The present application is a Continuation-In-Part of Ser. No. 12/174,894, filed Jul. 17, 2008, which is based on and claims the benefit of U.S. provisional patent application Ser. No. 60/950,182, filed Jul. 17, 2007, and U.S. provisional patent application Ser. No. 60/970,319, filed Sep. 6, 2007, the contents of which are hereby incorporated by reference in their entirety.

BACKGROUND OF THE INVENTION

The present invention relates to test equipment for electric vehicles. More specifically, the present invention relates to a tester for testing electrical systems of an electric vehicle.

Various types of electronic battery tester are known in the art. Electronic battery techniques have been pioneered by Midtronics, Inc. of Willowbrook, Ill. and Dr. Keith S. Champlin. Examples are shown and described in U.S. Pat. No. 3,873,911, issued Mar. 25, 1975, to Champlin; U.S. Pat. No. 3,909,708, issued Sep. 30, 1975, to Champlin; U.S. Pat. No. 4,816,768, issued Mar. 28, 1989, to Champlin; U.S. Pat. No. 4,825,170, issued Apr. 25, 1989, to Champlin; U.S. Pat. No. 4,881,038, issued Nov. 14, 1989, to Champlin; U.S. Pat. No. 4,912,416, issued Mar. 27, 1990, to Champlin; U.S. Pat. No. 5,140,269, issued Aug. 18, 1992, to Champlin; U.S. Pat. No. 5,343,380, issued Aug. 30, 1994; U.S. Pat. No. 5,572,136, issued Nov. 5, 1996; U.S. Pat. No. 5,574,355, issued Nov. 12, 1996; U.S. Pat. No. 5,583,416, issued Dec. 10, 1996; U.S. Pat. No. 5,585,728, issued Dec. 17, 1996; U.S. Pat. No. 5,589,757, issued Dec. 31, 1996; U.S. Pat. No. 5,592,093, issued Jan. 7, 1997; U.S. Pat. No. 5,598,098, issued Jan. 28, 1997; U.S. Pat. No. 5,656,920, issued Aug. 12, 1997; U.S. Pat. No. 5,757,192, issued May 26, 1998; U.S. Pat. No. 5,821,756, issued Oct. 13, 1998; U.S. Pat. No. 5,831,435, issued Nov. 3, 1998; U.S. Pat. No. 5,871,858, issued Feb. 16, 1999; U.S. Pat. No. 5,914,605, issued Jun. 22, 1999; U.S. Pat. No. 5,945,829, issued Aug. 31, 1999; U.S. Pat. No. 6,002,238, issued Dec. 14, 1999; U.S. Pat. No. 6,037,751, issued Mar. 14, 2000; U.S. Pat. No. 6,037,777, issued Mar. 14, 2000; U.S. Pat. No. 6,051,976, issued Apr. 18, 2000; U.S. Pat. No. 6,081,098, issued Jun. 27, 2000; U.S. Pat. No. 6,091,245, issued Jul. 18, 2000; U.S. Pat. No. 6,104,167, issued Aug. 15, 2000; U.S. Pat. No. 6,137,269, issued Oct. 24, 2000; U.S. Pat. No. 6,163,156, issued Dec. 19, 2000; U.S. Pat. No. 6,172,483, issued Jan. 9, 2001; U.S. Pat. No. 6,172,505, issued Jan. 9, 2001; U.S. Pat. No. 6,222,369, issued Apr. 24, 2001; U.S. Pat. No. 6,225,808, issued May 1, 2001; U.S. Pat. No. 6,249,124, issued Jun. 19, 2001; U.S. Pat. No. 6,259,254, issued Jul. 10, 2001; U.S. Pat. No. 6,262,563, issued Jul. 17, 2001; U.S. Pat. No. 6,294,896, issued Sep. 25, 2001; U.S. Pat. No. 6,294,897, issued Sep. 25, 2001; U.S. Pat. No. 6,304,087, issued Oct. 16, 2001; U.S. Pat. No. 6,310,481, issued Oct. 30, 2001; U.S. Pat. No. 6,313,607, issued Nov. 6, 2001; U.S. Pat. No. 6,313,608, issued Nov. 6, 2001; U.S. Pat. No. 6,316,914, issued Nov. 13, 2001; U.S. Pat. No. 6,323,650, issued Nov. 27, 2001; U.S. Pat. No. 6,329,793, issued Dec. 11, 2001; U.S. Pat. No. 6,331,762, issued Dec. 18, 2001; U.S. Pat. No. 6,332,113, issued Dec. 18, 2001; U.S. Pat. No. 6,351,102, issued Feb. 26, 2002; U.S. Pat. No. 6,359,441, issued Mar. 19, 2002; U.S. Pat. No. 6,363,303, issued Mar. 26, 2002; U.S. Pat. No. 6,377,031, issued Apr. 23, 2002; U.S. Pat. No. 6,392,414, issued May 21, 2002; U.S. Pat. No. 6,417,669, issued Jul. 9, 2002; U.S. Pat. No. 6,424,158,

issued Jul. 23, 2002; U.S. Pat. No. 6,441,585, issued Aug. 17, 2002; U.S. Pat. No. 6,437,957, issued Aug. 20, 2002; U.S. Pat. No. 6,445,158, issued Sep. 3, 2002; U.S. Pat. No. 6,456,045; U.S. Pat. No. 6,466,025, issued Oct. 15, 2002; U.S. Pat. No. 6,465,908, issued Oct. 15, 2002; U.S. Pat. No. 6,466,026, issued Oct. 15, 2002; U.S. Pat. No. 6,469,511, issued Nov. 22, 2002; U.S. Pat. No. 6,495,990, issued Dec. 17, 2002; U.S. Pat. No. 6,497,209, issued Dec. 24, 2002; U.S. Pat. No. 6,507,196, issued Jan. 14, 2003; U.S. Pat. No. 6,534,993, issued Mar. 18, 2003; U.S. Pat. No. 6,544,078, issued Apr. 8, 2003; U.S. Pat. No. 6,556,019, issued Apr. 29, 2003; U.S. Pat. No. 6,566,883, issued May 20, 2003; U.S. Pat. No. 6,586,941, issued Jul. 1, 2003; U.S. Pat. No. 6,597,150, issued Jul. 22, 2003; U.S. Pat. No. 6,621,272, issued Sep. 16, 2003; U.S. Pat. No. 6,623,314, issued Sep. 23, 2003; U.S. Pat. No. 6,633,165, issued Oct. 14, 2003; U.S. Pat. No. 6,635,974, issued Oct. 21, 2003; U.S. Pat. No. 6,707,303, issued Mar. 16, 2004; U.S. Pat. No. 6,737,831, issued May 18, 2004; U.S. Pat. No. 6,744,149, issued Jun. 1, 2004; U.S. Pat. No. 6,759,849, issued Jul. 6, 2004; U.S. Pat. No. 6,781,382, issued Aug. 24, 2004; U.S. Pat. No. 6,788,025, filed Sep. 7, 2004; U.S. Pat. No. 6,795,782, issued Sep. 21, 2004; U.S. Pat. No. 6,805,090, filed Oct. 19, 2004; U.S. Pat. No. 6,806,716, filed Oct. 19, 2004; U.S. Pat. No. 6,850,037, filed Feb. 1, 2005; U.S. Pat. No. 6,850,037, issued Feb. 1, 2005; U.S. Pat. No. 6,871,151, issued Mar. 22, 2005; U.S. Pat. No. 6,885,195, issued Apr. 26, 2005; U.S. Pat. No. 6,888,468, issued May 3, 2005; U.S. Pat. No. 6,891,378, issued May 10, 2005; U.S. Pat. No. 6,906,522, issued Jun. 14, 2005; U.S. Pat. No. 6,906,523, issued Jun. 14, 2005; U.S. Pat. No. 6,909,287, issued Jun. 21, 2005; U.S. Pat. No. 6,914,413, issued Jul. 5, 2005; U.S. Pat. No. 6,913,483, issued Jul. 5, 2005; U.S. Pat. No. 6,930,485, issued Aug. 16, 2005; U.S. Pat. No. 6,933,727, issued Aug. 23, 2005; U.S. Pat. No. 6,941,234, filed Sep. 6, 2005; U.S. Pat. No. 6,967,484, issued Nov. 22, 2005; U.S. Pat. No. 6,998,847, issued Feb. 14, 2006; U.S. Pat. No. 7,003,410, issued Feb. 21, 2006; U.S. Pat. No. 7,003,411, issued Feb. 21, 2006; U.S. Pat. No. 7,012,433, issued Mar. 14, 2006; U.S. Pat. No. 7,015,674, issued Mar. 21, 2006; U.S. Pat. No. 7,034,541, issued Apr. 25, 2006; U.S. Pat. No. 7,039,533, issued May 2, 2006; U.S. Pat. No. 7,058,525, issued Jun. 6, 2006; U.S. Pat. No. 7,081,755, issued Jul. 25, 2006; U.S. Pat. No. 7,106,070, issued Sep. 12, 2006; U.S. Pat. No. 7,116,109, issued Oct. 3, 2006; U.S. Pat. No. 7,119,686, issued Oct. 10, 2006; and U.S. Pat. No. 7,126,341, issued Oct. 24, 2006; U.S. Pat. No. 7,154,276, issued Dec. 26, 2006; U.S. Pat. No. 7,198,510, issued Apr. 3, 2007; U.S. Pat. No. 7,363,175, issued Apr. 22, 2008; U.S. Pat. No. 7,208,914, issued Apr. 24, 2007; U.S. Pat. No. 7,246,015, issued Jul. 17, 2007; U.S. Pat. No. 7,295,936, issued Nov. 13, 2007; U.S. Pat. No. 7,319,304, issued Jan. 15, 2008; U.S. Pat. No. 7,363,175, issued Apr. 22, 2008; U.S. Pat. No. 7,398,176, issued Jul. 8, 2008; U.S. Pat. No. 7,408,358, issued Aug. 5, 2008; U.S. Pat. No. 7,425,833, issued Sep. 16, 2008; U.S. Pat. No. 7,446,536, issued Nov. 4, 2008; U.S. Pat. No. 7,479,763, issued Jan. 20, 2009; U.S. Pat. No. 7,498,767, issued Mar. 3, 2009; U.S. Pat. No. 7,501,795, issued Mar. 10, 2009; U.S. Pat. No. 7,505,856, issued Mar. 17, 2009; U.S. Pat. No. 7,545,146, issued Jun. 9, 2009; U.S. Pat. No. 7,557,586, issued Jul. 7, 2009; U.S. Pat. No. 7,595,643, issued Sep. 29, 2009; U.S. Pat. No. 7,598,699, issued Oct. 6, 2009; U.S. Pat. No. 7,598,744, issued Oct. 6, 2009; U.S. Pat. No. 7,598,743, issued Oct. 6, 2009; U.S. Pat. No. 7,619,417, issued Nov. 17, 2009; U.S. Pat. No. 7,642,786, issued Jan. 5, 2010; U.S. Pat. No. 7,642,787, issued Jan. 5, 2010; U.S. Pat. No. 7,656,162, issued Feb. 2, 2010; U.S. Ser. No. 09/780,146, filed Feb. 9, 2001, entitled STORAGE BATTERY WITH INTEGRAL BATTERY TESTER; U.S. Ser. No. 09/756,638, filed Jan. 8, 2001, entitled METHOD AND

APPARATUS FOR DETERMINING BATTERY PROPERTIES FROM COMPLEX IMPEDANCE/ADMITTANCE; U.S. Ser. No. 09/862,783, filed May 21, 2001, entitled METHOD AND APPARATUS FOR TESTING CELLS AND BATTERIES EMBEDDED IN SERIES/PARALLEL SYSTEMS; U.S. Ser. No. 09/880,473, filed Jun. 13, 2001; entitled BATTERY TEST MODULE; U.S. Ser. No. 10/042,451, filed Jan. 8, 2002, entitled BATTERY CHARGE CONTROL DEVICE; U.S. Ser. No. 10/109,734, filed Mar. 28, 2002, entitled APPARATUS AND METHOD FOR COUNTERACTING SELF DISCHARGE IN A STORAGE BATTERY; U.S. Ser. No. 10/112,998, filed Mar. 29, 2002, entitled BATTERY TESTER WITH BATTERY REPLACEMENT OUTPUT; U.S. Ser. No. 10/263,473, filed Oct. 2, 2002, entitled ELECTRONIC BATTERY TESTER WITH RELATIVE TEST OUTPUT; U.S. Ser. No. 10/310,385, filed Dec. 5, 2002, entitled BATTERY TEST MODULE; U.S. Ser. No. 10/653,342, filed Sep. 2, 2003, entitled ELECTRONIC BATTERY TESTER CONFIGURED TO PREDICT A LOAD TEST RESULT; U.S. Ser. No. 09/653,963, filed Sep. 1, 2000, entitled SYSTEM AND METHOD FOR CONTROLLING POWER GENERATION AND STORAGE; U.S. Ser. No. 10/174,110, filed Jun. 18, 2002, entitled DAYTIME RUNNING LIGHT CONTROL USING AN INTELLIGENT POWER MANAGEMENT SYSTEM; U.S. Ser. No. 10/258,441, filed Apr. 9, 2003, entitled CURRENT MEASURING CIRCUIT SUITED FOR BATTERIES; U.S. Ser. No. 10/681,666, filed Oct. 8, 2003, entitled ELECTRONIC BATTERY TESTER WITH PROBE LIGHT; U.S. Ser. No. 10/791,141, filed Mar. 2, 2004, entitled METHOD AND APPARATUS FOR AUDITING A BATTERY TEST; U.S. Ser. No. 10/867,385, filed Jun. 14, 2004, entitled ENERGY MANAGEMENT SYSTEM FOR AUTOMOTIVE VEHICLE; U.S. Ser. No. 10/958,812, filed Oct. 5, 2004, entitled SCAN TOOL FOR ELECTRONIC BATTERY TESTER; U.S. Ser. No. 60/587,232, filed Dec. 14, 2004, entitled CELLTRON ULTRA, U.S. Ser. No. 11/018,785, filed Dec. 21, 2004, entitled WIRELESS BATTERY MONITOR; U.S. Ser. No. 60/653,537, filed Feb. 16, 2005, entitled CUSTOMER MANAGED WARRANTY CODE; U.S. Ser. No. 60/665,070, filed Mar. 24, 2005, entitled OHMMETER PROTECTION CIRCUIT; U.S. Ser. No. 60,694,199, filed Jun. 27, 2005, entitled GEL BATTERY CONDUCTANCE COMPENSATION; U.S. Ser. No. 11/178,550, filed Jul. 11, 2005, entitled WIRELESS BATTERY TESTER/CHARGER; U.S. Ser. No. 60/705,389, filed Aug. 4, 2005, entitled PORTABLE TOOL THEFT PREVENTION SYSTEM, U.S. Ser. No. 11/207,419, filed Aug. 19, 2005, entitled SYSTEM FOR AUTOMATICALLY GATHERING BATTERY INFORMATION FOR USE DURING BATTERY TESTER/CHARGING, U.S. Ser. No. 60/712,322, filed Aug. 29, 2005, entitled AUTOMOTIVE VEHICLE ELECTRICAL SYSTEM DIAGNOSTIC DEVICE, U.S. Ser. No. 60/713,168, filed Aug. 31, 2005, entitled LOAD TESTER SIMULATION WITH DISCHARGE COMPENSATION, U.S. Ser. No. 60/731,881, filed Oct. 31, 2005, entitled PLUG-IN FEATURES FOR BATTERY TESTERS; U.S. Ser. No. 60/731,887, filed Oct. 31, 2005, entitled AUTOMOTIVE VEHICLE ELECTRICAL SYSTEM DIAGNOSTIC DEVICE; U.S. Ser. No. 11/304,004, filed Dec. 14, 2005, entitled BATTERY TESTER THAT CALCULATES ITS OWN REFERENCE VALUES; U.S. Ser. No. 60/751,853, filed Dec. 20, 2005, entitled BATTERY MONITORING SYSTEM; U.S. Ser. No. 11/304,004, filed Dec. 14, 2005, entitled BATTERY TESTER WITH CALCULATES ITS OWN REFERENCE VALUES; U.S. Ser. No. 60/751,853, filed Dec. 20, 2005, entitled BATTERY MONITORING SYSTEM; U.S. Ser. No. 11/356,443, filed Feb. 16, 2006,

entitled ELECTRONIC BATTERY TESTER WITH NETWORK COMMUNICATION; U.S. Ser. No. 11/498,703, filed Aug. 3, 2006, entitled THEFT PREVENTION DEVICE FOR AUTOMOTIVE VEHICLE SERVICE CENTERS; U.S. Ser. No. 11/511,872, filed Aug. 29, 2006, entitled AUTOMOTIVE VEHICLE ELECTRICAL SYSTEM DIAGNOSTIC DEVICE; U.S. Ser. No. 11/519,481, filed Sep. 12, 2006, entitled BROAD-BAND LOW-CONDUCTANCE CABLES FOR MAKING KELVIN CONNECTIONS TO ELECTROCHEMICAL CELLS AND BATTERIES; U.S. Ser. No. 60/847,064, filed Sep. 25, 2006, entitled STATIONARY BATTERY MONITORING ALGORITHMS; U.S. Ser. No. 11/641,594, filed Dec. 19, 2006, entitled METHOD AND APPARATUS FOR MEASURING A PARAMETER OF A VEHICLE ELECTRONIC SYSTEM; U.S. Ser. No. 11/711,356, filed Feb. 27, 2007, entitled BATTERY TESTER WITH PROMOTION FEATURE; U.S. Ser. No. 11/811,528, filed Jun. 11, 2007, entitled ALTERNATOR TESTER; U.S. Ser. No. 60/950,182, filed Jul. 17, 2007, entitled BATTERY TESTER FOR HYBRID VEHICLE; U.S. Ser. No. 60/973,879, filed Sep. 20, 2007, entitled ELECTRONIC BATTERY TESTER FOR TESTING STATIONARY BATTERIES; U.S. Ser. No. 11/931,907, filed Oct. 31, 2007, entitled BATTERY MAINTENANCE WITH PROBE LIGHT; U.S. Ser. No. 60/992,798, filed Dec. 6, 2007, entitled STORAGE BATTERY AND BATTERY TESTER; U.S. Ser. No. 12/099,826, filed Apr. 9, 2008, entitled BATTERY RUN DOWN INDICATOR; U.S. Ser. No. 61/061,848, filed Jun. 16, 2008, entitled KELVIN CLAMP FOR ELECTRONICALLY COUPLING TO A BATTERY CONTACT; U.S. Ser. No. 12/168,264, filed Jul. 7, 2008, entitled BATTERY TESTERS WITH SECONDARY FUNCTIONALITY; U.S. Ser. No. 12/174,894, filed Jul. 17, 2008, entitled BATTERY TESTER FOR ELECTRIC VEHICLE; U.S. Ser. No. 12/204,141, filed Sep. 4, 2008, entitled ELECTRONIC BATTERY TESTER OR CHARGER WITH DATABUS CONNECTION; U.S. Ser. No. 12/328,022, filed Dec. 4, 2008, entitled STORAGE BATTERY AND BATTERY TESTER; U.S. Ser. No. 12/416,457, filed Apr. 1, 2009, entitled SYSTEM FOR AUTOMATICALLY GATHERING BATTERY INFORMATION; U.S. Ser. No. 12/416,453, filed Apr. 1, 2009, entitled INTEGRATED TAG READER AND ENVIRONMENT SENSOR; U.S. Ser. No. 12/416,445, filed Apr. 1, 2009, entitled SIMPLIFICATION OF INVENTORY MANAGEMENT; U.S. Ser. No. 12/485,459, filed Jun. 16, 2009, entitled CLAMP FOR ELECTRONICALLY COUPLING TO A BATTERY CONTACT; U.S. Ser. No. 12/498,642, filed Jul. 7, 2009, entitled ELECTRONIC BATTERY TESTER; U.S. Ser. No. 12/697,485, filed Feb. 1, 2010, entitled ELECTRONIC BATTERY TESTER; U.S. Ser. No. 12/698,375, filed Feb. 2, 2010, entitled ELECTRONIC BATTERY TESTER; U.S. Ser. No. 12/712,456, filed Feb. 25, 2010, entitled METHOD AND APPARATUS FOR DETECTING CELL DETERIORATION IN AN ELECTROCHEMICAL CELL OR BATTERY; U.S. Ser. No. 61/311,485, filed Mar. 8, 2010, entitled BATTERY TESTER WITH DATABUS FOR COMMUNICATING WITH VEHICLE ELECTRICAL SYSTEM U.S. Ser. No. 61/313,893, filed Mar. 15, 2010, entitled USE OF BATTERY MANUFACTURE/SELL DATE IN DIAGNOSIS AND RECOVERY OF DISCHARGED BATTERIES; which are incorporated herein in their entirety.

Many electric vehicles use a storage battery pack or other electrical storage device, to store energy for use in operating the electric vehicle. Some such electric vehicles use energy recovery (or "regeneration") techniques in which potentially waste energy is recovered and stored in the energy storage device. One example is recovery of energy from braking

function. The energy in braking is recovered as electrical energy rather than being dissipated as excess heat. Preferably, the energy storage device is able to efficiently store the excess energy, as well as deliver energy to an electrical motor of the electric vehicle. Due to the increasing price of petroleum, hybrid systems are rapidly proliferating. There is an ongoing need to test the electrical systems of such electric vehicles.

SUMMARY OF THE INVENTION

Testing or diagnostics are performed on an electric vehicle. The vehicle is operated and current flow through a system of the vehicle is monitored. A voltage related to the system is also monitored. Diagnostics are provided based upon the monitored voltage and the monitored current.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a simplified block diagram showing a battery tester in accordance with the present invention coupled to a electric vehicle.

FIG. 2 is a simplified block diagram showing steps in accordance with the present invention.

FIG. 3 is a simplified block diagram which illustrates a test device in accordance with the present invention.

FIG. 4 is a simplified block diagram showing one aspect of the present invention in which the test device couples to the databus of the electric vehicle.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

Electric vehicles and hybrid vehicles are becoming increasingly popular as an alternative to traditional vehicles which are powered solely by an internal combustion engine. In a electric vehicle, a large battery or a group of batteries, or other energy storage device, is used to store electrical energy. The stored electrical power is used by an electric motor to power the electric vehicle.

In order to increase energy efficiency, some electric vehicles use various techniques to capture or otherwise recover waste energy. This may be referred to as "regeneration". The recovered energy is typically returned in the battery of the electric vehicle for storage and subsequent use.

Various techniques are used to recover energy. For example, one common technique is to use the braking system of the electric vehicle to convert vehicle motion into electricity for storage in the battery. This differs from a conventional braking system in which excess energy is vented into the atmosphere as heat.

As the battery of the electric vehicle ages, its ability to store energy also degrades. However, this may not be apparent to the operator, particularly in a hybrid vehicle. One symptom of a failing battery is decreased mileage of the electric vehicle because the battery is not able to effectively store or deliver energy. The health of a battery in a electric vehicle is an indication of how well the battery accepts a charge and is able to deliver stored energy at high discharge rates. To some extent, this relates to the amp hour capacity of the battery as well as the ability of the battery to accept or deliver charge in a given time. This is related to how much recovered energy can be stored at one time for use at a later time. For example, is the battery capable of storing energy from many braking cycles for subsequent use, or is it only able to store energy from a few such braking cycles.

Typical battery testing techniques are difficult to implement in such a electric vehicle. For example, it may be diffi-

cult or impossible to access the individual batteries of a battery pack for testing. Such access may require a great deal of labor. Further, there may be safety concerns related to the relatively high voltages involved if the battery pack is disassembled for testing.

With the present invention, a current sensor is coupled to the battery pack of a electric vehicle of the type which includes an electric motor to move the electric vehicle. The current sensor can be placed in line with the battery pack and arranged to measure current into and out of the pack. The total string voltage of the battery pack is also measured. A technician or other service personnel performs a battery test by operating the electric vehicle through a number of braking and acceleration cycles. Data is collected and compared to baseline or nominal data which is representative of operation of a new electric vehicle. An output can be provided based upon the comparison. For example, the output can be an indication of how well the electric vehicle compares to new electric vehicle, for example as a percentage.

The current sensor can be placed in series with one of the battery terminals using a shunt resistance or the like. Another example is a Hall effect or other non-intrusive sensor. Such a sensor is advantageous because it does not require the battery to be disconnected. In another example, an adapter can be configured which can be inserted between the battery pack and the electric vehicle such that the test device can be coupled to the battery.

The various sensors can be coupled at any convenient location, for example, proximate the battery pack, under the hood, near the electric vehicle motor or other electronics. In such an application, a Hall effect sensor may be sufficient because of the relatively large magnitudes of the current levels being monitored. Further, a Hall effect sensor may be easily "zeroed" because during installation there will be no current flowing. Voltage measurements may be made using direct attachment, for example, to the high voltage pole of the battery. The voltage and current measurements may also be obtained through other techniques, for example, through an OBDII interface used to read electrical parameters from the electric vehicle computer system.

During testing, the test device can provide instructions to an operator as to how to operate the electric vehicle. Such instructions can be provided, for example, through a wireless communication link to a device proximate the operator, through a PDA-type device, through audible instructions, through a display of the vehicle, or through other techniques.

If the testing device couples to the OBDII system of the electric vehicle, additional information can be retrieved. For example, information related to the speed (RPM) of a motor, speed of the electric vehicle, braking information, etc. can be recovered. With this additional information, the test device may be used to verify that the technician has performed the required operations. Such operations should have some flexibility in order to reflect safe driving conditions.

FIG. 1 is a simplified block diagram 10 of a electric vehicle 12 coupled to a test device 14. The test device is shown as locate separate from the electric vehicle 12 and may be a portable or stationary device. However, in some configurations the test device 14 may be included in electric vehicle 12. Electric vehicle 12 is illustrated as including battery pack 20, electric motor 22 and energy recovery device 24. As discussed, the battery pack 20 is used to power the electric motor 22 while the energy recover device 24 is used to recover energy during electric vehicle operation. Test circuitry 14 couples to battery 20 and includes or is coupled to voltage sensor 30, memory 32 and microprocessor 33. Further, test circuitry 14 includes or is coupled to a current sensor 34

7

arranged to sensor current into and/or out of battery pack 20. Test circuitry 14 provides an output through input/output (I/O) 35 as discussed above related to the condition of the battery pack 20. The test circuitry 14 includes a microprocessor 33 or the like which may include either internal or external analog to digital converters configured to convert the sensed voltage current levels to digital values. Microprocessor 33 operates in accordance with instructions stored in memory and provide an output 35 which is related to the condition of the battery pack 20. FIG. 1 also shows an optional internal combustion engine 40 which is used to supplement the energy delivered by battery pack 20. The optional engine 40 can be used to charge battery pack 20, and/or can be used to supplement the electrical power available to motor 22 during times of high acceleration or the like. Thus, engine 40 may include an electric generator 41. Similarly, engine 40 can be configured to provide power directly to wheels or other components of the vehicle 12. The connection of test device 14 to the vehicle 12 may be through an electrical connection to sensors such as the voltage sensor 30 and the current sensor 34. Additionally, the voltage sensor 30 and current sensor 34 can comprise components within the vehicle 12. In such a configuration, test device 14 can couple to the vehicle through a data connection to the vehicle, for example, an OBDII connection to the vehicle in which current and voltage information are read back from the vehicle. For example, the data can be recovered as it is transmitted on the vehicle databus or the data can be retrieved by placing commands on the databus to access the desired information.

FIG. 2 is a simplified block diagram showing steps in accordance with one example embodiment of the present invention. The block diagram of FIG. 2 begins at start block 50 and controls past block 52 where the electric vehicle is operated and data is collected. At block 54, nominal data is recovered. For example, such nominal data can be stored in memory 32 shown in FIG. 1. The nominal data can be related to a baseline condition, for example, the condition of the battery pack and/or in electric vehicle 12 when they are new. At block 56, the collected data is compared to the nominal data and an output is provided at block 58. The output can be, for example, a relative output with respect to the current condition of electric vehicle in battery relative to a new electric vehicle or battery. This may be in the form of, for example, a percentage or other format. At block 60, the process is terminated.

FIG. 3 is a simplified block diagram showing test device 14 in greater detail. Test device 14 is illustrated as including differential amplifier 102 which couples to current sensor 34. A second differential amplifier 98 couples to battery 20 and forms the voltage sensor 30. The voltage sensor 30 may be a part of, or may be separated from, the test device 14. The output from the amplifier 98 is provided to an analog to digital converter 100 which couples microprocessor 33. Similarly, the output of amplifier 102 is converted into a digital format for microprocessor 33 using analog to digital converter 104. The actual voltage and current sensors may be in accordance with any technique and are not limited to the techniques described herein. As discussed below, the current and voltage sensors may be a part of vehicle 12 and the test can retrieve their information over a databus of the vehicle.

Microprocessor 33 operates in accordance with instructions stored in memory 32 and is configured to communicate with an operator through user input/output (I/O) 110. An optional OBDII interface, as illustrated at OBDII I/O 112, is provided. OBDII I/O 112 is configured to couple to the OBDII databus of the electric vehicle 12. The user I/O 110 can be any type of user input and output including, for example, a

8

button or keypad entry, a display including a graphical display, an audio output including voice prompts, or other input or output techniques.

FIG. 4 is a simplified block diagram showing another aspect of the present invention. As discussed above, test device 14 couples to the on board databus 130 of electric vehicle 12, for example through OBDII connector 132. Electric vehicle 12 is illustrated as including a plurality of systems identified as System A, B, C through System N. These systems can be any active or passive electrical component or set of components within the vehicle including a motor or motors of the vehicle, an energy recovery system such as a regenerative braking system, a battery cell, a block of cells, a battery pack, vehicle electronics such as audio systems, defrosters, wipers, adjustable seat motors, seat heaters, internal and external lights, computer systems, electrical systems associated with an electric or internal combustion motor, charging systems, or others. Each of the systems A-N is illustrated as having a current sensor 140A-140N, respectively and a voltage sensor 142A-142N, respectively. The multiple current sensors 140 and voltage sensors 142 are provided for illustrative purposes only and a particular system within the vehicle may have neither type of sensor, may have a single sensor, or may have multiple sensors. The outputs from the current sensors 140 the voltage sensors 142 are provided to the internal databus of the electric vehicle 130. The electric vehicle 12 may include additional sensors for sensing physical properties such as temperature, moisture content, fluid levels, pressures, speed or rate of rotation of motors, flow rate, whether a switch is opened or closed, etc. These sensors are illustrated in FIG. 4 as sensor A, B through sensor N and are also coupled to the databus 130 of electric vehicle 12. The sensors A, B, . . . N may be associated with any of the above discussed systems A-N, or with other components or aspects of the electric vehicle 12. For example, a particular sensor may provide a temperature reading of a particular system, or other measurement related to the system. Note that the coupling of the various sensors to the databus 130 may be direct or indirect. For example, data from a particular sensor may be provided to another component, such as directly to a microprocessor 150 of the electric vehicle. Subsequently, the microprocessor 150 may provide the information on databus 130. The data from the various sensors may be optionally stored in an internal memory 152 of the electric vehicle 12. In FIG. 4, the memory 152 is illustrated as being coupled to microprocessor 150. However, this may be optional and the memory 152 can be coupled to databus 130, either directly or through some other component. In one aspect of the present invention, test device 14 monitors information from sensors within the electric vehicle in order to provide enhanced diagnostics without requiring connection of additional sensors to the electric vehicle 12. This is achieved by retrieving data through the databus 130 of the electric vehicle as the various sensors within the vehicle communicate information.

In measuring electrical parameters of components, it is often desirable to couple to the electrical component through a four point "Kelvin" connection. In such a configuration, a first pair of connections are used to measure a voltage across the component while a second pair of connections are used to carry current. Kelvin connections reduce errors in the measurements associated with the electrical leads and wiring which are used to couple to the component. However, in many electric vehicles, it is extremely difficult to place Kelvin connectors onto the various electrical components. Further, even if such connections are made, they may carry high voltages which may be unsafe for an operator. Therefore, it is often difficult to couple to the electrical systems of an electric

vehicle using traditional Kelvin connection techniques which have been associated with the automotive industry.

In one aspect, the present invention provides a “virtual Kelvin” connection to electrical components of the vehicle. The “virtual Kelvin” connection is embodied in microprocessor 33 of the test device 14. Microprocessor 33 receives current and voltage information from a pair of sensors, such as current sensor 140A and voltage sensor 142A, which are coupled to a component of the electric vehicle 12 such as system A. Using this information, the microprocessor 33 is capable of calculating an electrical parameter associated with that particular system. For example, electrical resistance can be calculated using Ohms’ law as $R=V/I$. However, other electrical parameters can be calculated such as conductance. Further still, if the electricity through the system has a time varying component, it is possible to determine dynamic parameters of the system such as dynamic resistance or conductance. Complex parameters such as impedance, reactance, etc. of the particular system can also be determined. Note that there may be a lag or time delay between the two measurements (voltage and current) due to delays in the databus 130 or due to other causes. Microprocessor 33 can compensate for such a lag by determining, or at least approximating, the duration of the delay. One technique which can be used is to monitor a function or activity within the vehicle, for example, a braking function, while monitoring the outputs from the associated current and voltage sensors. Based upon when the current and voltage begin to change relative to one another, it is possible to compensate for any delays if the relationship is known. For example, the voltage and current may be expected to rise simultaneously in some systems. If there is a lag in the voltage measurement, for example, the duration of that lag can be measured by microprocessor 33 and used to compensate subsequent measurements. Similarly, a particular sensor may have a relatively long response time, or the databus 130 may be of a sufficiently slow data rate that sufficient band width may not be available to measure or monitor a rapidly changing voltage or current. Again, compensation techniques can be used to at least partially address such a shortcoming, for example, by providing a compensated frequency response profile for a particular sensor. This information can be used to characterize a particular sensor or measurement performed using a set of sensors. This characterization can compensate for such measurements in use to thereby improve the accuracy of the measurement. The compensation characterization can be determined experimentally and thereby stored in the test device 14, or can be determined empirically by monitoring operation of the vehicle 12 as discussed above. This characterization information can be stored in memory 32 of test device 14 and use to compensate the measured parameters.

During operation, microprocessor 33 collects data from a desired system (A-N) of electric vehicle 12 using the associated current sensor 140A-N and/or voltage sensor 140A-N as desired. The microprocessor 33 can also use information collected from other sensors of the electric vehicle, such as sensors A-N for use in testing as desired. If a measurement is desired across multiple systems, it is possible to add or subtract the measured currents and voltages to obtain such a measurement, depending upon the configuration of the sensors. As discussed above, the data is retrieved from databus 130 using OBDII I/O circuitry 112 coupled to the databus 130 through OBDII connector 132. In addition to having a user input/output 110, another optional input/output (I/O) 160 is illustrated. I/O 160 can comprise circuitry for providing data to, or receiving data from, another device such as a remote location which collects data or measurements, a printer, a

remote control or display for use by an operator, remote sensors, etc. Additionally, other optional sensors 162 are shown in test device 14 of FIG. 4. Sensors 162 may comprise other sensors used to perform diagnostics including physical Kelvin connectors, current and/or voltage sensors, temperature sensors, etc. The user I/O circuitry 110 can be used to provide an interface for an operator during testing of electric vehicle 12. For example, the operator can provide information to the test device 14 related to which of the systems of electric vehicle 12 to test, to a selected test to perform, to provide information regarding electric vehicle 12, etc. The I/O circuitry 110 can also be used to provide information to the operator such as the results of a test, intermediary test results, information regarding past tests, information regarding the electric vehicle 12, information regarding the history of the vehicle 12 or other information. Additionally, if a particular test requires the electric vehicle 12 to be operated in a particular manner, the user I/O circuitry 110 can provide instructions to the operator. For example, the particular test being performed may require that the electric vehicle 12 be accelerated, or that the brake be applied, that the electric vehicle be stopped for a period, or other actions. The instructions to an operator may be in the form of, for example, audible or visual instructions which may be easily received when operating the electric vehicle 12. Using the data collected from the sensors, microprocessor 33 can diagnose individual systems and the overall operation of electric vehicle 12. In one example of the present invention, the information can be used to perform any type of diagnostics such as those known in the art. Various types of diagnostics include measuring parameters of systems of the electric vehicle 12, monitoring the amount of energy recovered during an energy regenerative process such as by recovering energy during a braking function, determining the maximum amount of energy which may be recovered, or the maximum amount of energy which the energy storage device can accept at any one time during recharging, monitoring the energy storage device as it ages to identify a loss of the capacity to store recovered energy or the overall capacity of the storage device 20, monitoring the maximum energy which the energy storage device 20 is capable of delivering, etc.

For example, one diagnostic technique includes monitoring a parameter of a cell or block of cells of the battery pack 20 and observing changes over time, for example changes in impedance, conductance, resistance, or other parameters including dynamic parameters. Another example diagnostic includes comparing parameters measured for a particular cell or block of cells of the battery pack 20 and observing any imbalances between cells or blocks of cells, or other indications that a particular cell or block of cells is not operating in a manner which is similar to the remaining cells or blocks of cells. This may be through statistical techniques such as observing the distribution of measurements of cells or blocks of cells, etc. Another example diagnostic technique is simply observing voltage differences across cells or blocks of cells in the battery 20.

In another example, the user I/O 110 is used to provide an output related to carbon dioxide emissions of the electric vehicle 12. For example, the output can be an indication of the reduction in carbon dioxide emissions of the electric vehicle 12 in comparison to a standard vehicle with an internal combustion engine. In a related example, the amount of energy regenerated by electric vehicle 12, for example using a regenerative braking technique, can be monitored using test device 14 and an output provided using user I/O 110 which indicates

11

the equivalent amount of carbon dioxide which would have been generated by typical internal combustion engine had the energy not been recovered.

In another example configuration, test device **14** can be used to monitor operation of electric vehicle **12** and collect information related to the efficiency of the electric vehicle **12** under different operating conditions. This information is then used by device **14** to instruct an operator through user I/O **110** to operate the electric vehicle **12** in a manner which increases efficiency. For example, if system A shown in FIG. 4 comprises a regenerative braking system, and system B is the battery pack **20** for the electric vehicle **12**, the test device **14** can be configured to monitor the energy recovered by the regenerative braking system and the amount of energy which the battery pack **20** is capable of storing. Thus, if measurements indicate that the battery pack **20** is only capable of accepting a maximum of 50 kW, the test device **14** can instruct the operator when braking to attempt to rapidly approach the 50 kW energy recovering level, and maintain the 50 kW level for an extended period without exceeding that level. This will ensure that the maximum amount of energy is recovered during a braking operation. Similar techniques can be used to instruct the operator during acceleration periods, idling periods, "stop and go" traffic, etc. In a more advanced configuration, the device **14** is configured to control operation of the systems in vehicle **12** in a manner which differs from the configuration provided by the vehicle control system, for example, as implemented in the microprocessor **150** of electric vehicle **12**. For example, the test device **14** can provide instructions or information on databus **130** which allows the charging system or the regeneration system of electric vehicle **12** to charge the battery pack **20** to a higher or lower level than that set by the internal control system of the vehicle. This may be used, for example, to extend the life of systems within the vehicle, increase the range of the vehicle, test certain systems, or for other functions or purposes.

The particular test performed by the test device **14** can be a simple evaluation and indicate and good or bad battery pack **14**, or can provide more detailed information such as the total battery pack dynamic conductance or impedance, or a dynamic parameter related to an individual cell or group of cells in the pack **20**, etc. During testing, the device **14** can communicate with the operator to instruct the operator to perform a particular operation with the vehicle, such as aggressive acceleration or deceleration. This can be communicated through an audible or visual technique that does not interfere with vehicle operation such as lights, voice prompts, tones or sounds, etc. this may be communicated to the operator using I/O components that are a part of vehicle **12**, for example, a vehicle speaker, display, etc. In one configuration, the device **14** instructs the driver to operate the vehicle **12** in a safe manner. If temperature data is available, for example through a temperature sensor, the test measurements can be compensated based upon temperature. If an external PDA or cellular "smart phone" type device is used, the interface with the operator can be provided through such a device. For example, in one configuration, the user I/O such as element **110** shown in FIG. 3, comprises a remote device such as a "smart phone" capable of communicating with an operator. Communication with the "smart phone" can be through wireless communication techniques such as WiFi, Bluetooth, cellular network, etc., or can be through wired techniques such as a data cable or other connection.

The test device **14** can be configured to recognize when certain conditions have been met by monitoring, for example, engine speed (RPM), vehicle miles per hour, vehicle acceleration and deceleration, etc. This can be by using instru-

12

ments onboard the vehicle **12** such as GPS information, the output from a speedometer, etc. Once a complete data set has been obtained as desired for a particular test, the test device **14** can provide an output accordingly. The test can be modified based upon driving conditions and the duration of the test can be extended as needed. Instructions can be provided to the operator and, in some configurations, the operation of the vehicle **12** can be controlled by the test device **14**. For example, gearing or braking of vehicle **12** can be controlled, requesting the vehicle **12** enter "EV" mode, operating certain accessories on the vehicle, monitoring acceleration or braking, monitoring torque provided by vehicle motors, engine parameters such as fuel mix, etc can be monitored or controlled, or other elements controlled or monitored as desired. The operator can be informed that the vehicle **12** is being operated correctly or incorrectly using an audible or visual output. Any "trouble codes" available on the databus of vehicle **12** can also be incorporated into the testing. One type of test involves the vehicle **12** being "blocked", in other words placed onto a test stand in which the vehicle **12** is operated on rollers. The test device **14** can be configured to operate in such a mode for use in monitoring acceleration and deceleration tests, etc. If the test device **14** is temporarily coupled to the vehicle **12**, it can be configured to be left in the vehicle **12** for an extended period while an operator drives the vehicle **12** under normal operating conditions. This allows the vehicle **12** to be monitored during "real life" drive cycles as data is collected. In one configuration, the test device **15** monitors instantaneous fuel usage and combines this fuel usage with a battery test. This information can be useful in identifying bad battery packs or battery within the pack **20** and used to monitor the efficiency of the charging cycle. A poor charging cycle indicates a bad battery and will result in increased fuel usage. The test device **14** can record the fuel usage, the number of starts, or other information and store such information in a flash memory for subsequent recovery.

Although the present invention has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention. For example, although storage batteries or a "battery pack" described, as used herein the term electric energy storage device includes a battery or collection of batteries, capacitors including supercapacitors and ultracapacitors, and other electrical energy storage devices. As used herein, electric vehicle includes any type of vehicle which uses an electric motor to propel, or assist in propelling, the vehicle. One example electric vehicle is a vehicle with an electric motor and an electric storage device such as a battery pack or the like. Another example electric vehicle is an electric vehicle with regenerative techniques in which energy is recovered, for example, from the braking process. Another example electric vehicle is a hybrid vehicle which also includes an internal combustion engine for use in supplementing electric power, and/or charging the electrical energy storage device. Such a hybrid vehicle may optionally include regenerative systems for energy recovery. As used herein, "operating" an electric vehicle includes using the vehicle, or systems of the vehicle, and is not limited to driving the vehicle. In one configuration the test device is separate from the vehicle and may be selectively coupled to the vehicle or added after manufacture of the vehicle. The "virtual" Kelvin configuration can be used to calculate a parameter of a system of the vehicle using two or more inputs from sensors which are transmitted over a databus of the vehicle.

13

What is claimed is:

1. A method of testing an electrical system of an electric vehicle, comprising:

operating the electric vehicle;

coupling a test device to a databus of the electric vehicle;

monitoring data on the databus and retrieving information related to current flowing into a system of the electric vehicle with the test device during the step of operating;

monitoring data on the databus and retrieving information from a sensor of the vehicle related to a voltage of the electrical system with the test device during the step of operating;

providing instructions to an operator which instruct the operator to operate the electrical vehicle in a specific manner;

recognizing when certain conditions have been met with the test device during the step of operating the vehicle; and

diagnosing the electric vehicle with the test device based upon the monitored current and the monitored voltage.

2. The method of claim 1 wherein diagnosing includes comparing monitored current and monitored voltage with nominal values.

3. The method of claim 1 including wirelessly communicating the retrieved information to a mobile device.

4. The method of claim 1 wherein the databus comprises an OBDII databus.

5. The method of claim 1 wherein the system comprises a battery pack of the vehicle.

6. The method of claim 5 including monitoring a second system of the vehicle.

7. The method of claim 6 wherein the second system comprises a regenerative braking system of the vehicle.

8. The method of claim 7 wherein diagnosing comprises monitoring energy output from the regenerative braking system and monitoring energy input into the battery pack.

9. The method of claim 8 wherein the diagnosing further comprises determining efficiency of a transfer of energy recovered from the regenerative braking system and stored in the battery pack.

10. The method of claim 1 wherein the system comprises a block of cells of a battery pack of the electric vehicle.

11. The method of claim 10 including monitoring a second block of at least one or more cells of the battery pack.

12. The method of claim 11 wherein the diagnosing comprises comparing a parameter of the first block of cells with a parameter of the second block of cells.

13. The method of claim 1 wherein the diagnosing comprises measuring a parameter of the system.

14. The method of claim 13 wherein the parameter comprises a dynamic parameter.

15. The method of claim 1 including providing an output to an operator of the electric vehicle.

16. The method of claim 15 wherein the output comprises instructions related to operation of the vehicle for use in performing the step of diagnosing.

17. The method of claim 1 wherein the electric vehicle comprises a hybrid vehicle.

18. The method of claim 17 wherein the system comprises an electric generator coupled to an internal combustion engine of the electric vehicle.

19. The method of claim 18 including monitoring a second system of the electric vehicle, wherein the second system comprises a battery pack and the step of diagnosing comprises determining efficiency of storage of energy from the generator by the battery pack.

14

20. The method of claim 1 wherein the diagnosing includes compensating for a difference between retrieving information related to current flowing into the system and retrieving information related to the voltage of the system.

21. The method of claim 1 including placing information onto the databus which affects operation of the electric vehicle.

22. The method of claim 1 including placing information onto the databus which affects operation of a system of the electric vehicle.

23. The method of claim 1 including providing an output to an operator of the vehicle to instruct the operator to operate the vehicle in a manner to increase energy efficiency of the vehicle.

24. An apparatus for testing an electric vehicle, comprising:

a databus connector configured to connect to a databus of the electric vehicle;

a microprocessor configured to:

retrieve voltage information from the databus of the electric vehicle provided by a voltage sensor of the vehicle coupled to an electrical system of the electric vehicle;

retrieve current information from the databus of the electric vehicle provided by a current sensor of the vehicle coupled to the electrical system of the electric vehicle;

instruct an operator to operate the electrical vehicle in a specified manner;

recognize when certain conditions have been met during the step of operating by monitoring the vehicle; and

diagnose the operation of the vehicle based upon the retrieved current information and the retrieved voltage information.

25. The apparatus of claim 24 wherein the microprocessor compares monitored current and monitored voltage or a function of monitored voltage and monitored current, with nominal values.

26. The apparatus of claim 24 wherein the databus comprises an OBDII databus.

27. The apparatus of claim 24 wherein the system comprises a battery pack of the vehicle.

28. The apparatus of claim 27 wherein the microprocessor monitors a second system of the vehicle.

29. The apparatus of claim 28 wherein the second system comprises a regenerative braking system.

30. The apparatus of claim 29 wherein the microprocessor monitors energy output from the regenerative braking system and monitors energy input into the battery pack.

31. The apparatus of claim 30 wherein the microprocessor further determines efficiency of the transfer of energy recovered from the regenerative braking system and stored in the battery pack.

32. The apparatus of claim 24 wherein the system comprises a block of one or more cells of a battery pack of the electric vehicle.

33. The apparatus of claim 32 wherein the microprocessor monitors a second block of one or more cells of the battery pack.

34. The apparatus of claim 33 wherein the microprocessor compares a parameter of the first block of cells with a parameter of the second block of cells.

35. The apparatus of claim 34 wherein the microprocessor measures a parameter of the system.

36. The apparatus of claim 35 wherein the parameter comprises a dynamic parameter.

37. The apparatus of claim 24 including an output provided to an operator of the electric vehicle.

15

38. The apparatus of claim 24 wherein the electric vehicle comprises a hybrid vehicle.

39. The apparatus of claim 24 wherein the system comprises an electric generator coupled to an internal combustion engine of the electric vehicle.

5

40. The apparatus of claim 39 wherein the microprocessor monitors a second system of the electric vehicle, wherein the second system comprises a battery pack and the microprocessor determines efficiency of storage of energy from the generator by the battery pack.

10

41. The apparatus of claim 24 wherein the microprocessor compensates for a difference between retrieving information related to current flowing into the system and retrieving information related to a voltage of the system.

42. The apparatus of claim 24 wherein the microprocessor is configured to place information onto the databus which affects operation of the electric vehicle.

15

* * * * *

16